ABSTRACT

Title of Document: COMPARING AND CONTRASTING DIFFERENT METHODS FOR PROBING STUDENT EPISTEMOLOGY AND EPISTEMOLOGICAL DEVELOPMENT IN INTRODUCTORY PHYSICS

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In this dissertation, I perform and compare three different studies of introductory physics students' epistemological views – their views about the nature of knowledge and how it is learned. Physics education research (PER) shows that epistemological views affect how students learn, so they are important to understand and diagnose. The first study uses a Likert-scale instrument, adapted from the Maryland Physics Expectation Survey, designed to assess to what extent students see physics knowledge as coherent (rather than piecemeal), conceptual (rather than just formulas), and constructed (rather than absorbed). Using this survey, I documented several results, including that (i) a large lecture class *can* produce favorable changes in students' epistemological views, at least in the context of the class, and (ii) teaching a rushed

modern physics unit at the end of an introductory sequence can lead to negative epistemological effects. The second study uses the Force Concept Inventory with modified instructions: students indicated both the answer they think a scientist would give and the answer that makes the most sense to them personally. A "split" between these two answers shows that the student does not think she has reconciled her common sense with the formal physics concepts. This study showed that attention to reconciliation in a course allows students to see initially-counterintuitive ideas as making sense. Finally, I did a detailed study of one student by (i) watching video of her in tutorial, where she and three other students answered a structured series of conceptual and quantitative physics questions, (ii) formulating interviews based largely on what I observed in the video, and (iii) interviewing her while the tutorial was still fresh in her head. I repeated this cycle every week for a semester. I found that her tendency to focus on the multiple and ambiguous meanings of words like "force" hampered her ability to reconcile physics concepts with common sense. This last method is time-consuming, but it produces rich data and allows for a fine-grained analysis of individual students. The first two survey methods are best suited for measuring the effect of epistemologically-centered course reforms on large groups of students.

COMPARING AND CONTRASTING DIFFERENT METHODS FOR PROBING STUDENT EPISTEMOLOGY AND EPISTEMOLOGICAL DEVELOPMENT IN INTRODUCTORY PHYSICS

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Chapter 1: Physics Education Research and Epistemology

The best short description of education research I have ever heard came from a recent conference talk I attended by Redish, where he reiterated larger points made in a Millikan lecture (Redish 1999). In it, he mentioned that many people see teaching as an art form, and education research has the goal of transforming that art into a science. Actually, art, science, and teaching are similar in many ways: all require insight, creativity, thought, and practice. A discipline like performance art, for example, has a reputation for requiring "natural talent" (whatever that means) to succeed. Many people perceive teaching as having a similar reputation. By resting aspects of teaching upon scientifically determined principles, education researchers seek to understand how students learn and how instructors might teach them more effectively. This dissertation is a small part of that effort.

Physics Education Research

Physics education research (PER) emerged as a discipline a few decades ago. The first large bodies of work concerned how students learned conceptual ideas in introductory physics. By probing student understanding before and after lessons, adjusting the curriculum in thoughtful ways, and iterating this process over time, researchers isolated common conceptual difficulties and discussed ways teachers might deal with them. This research model continues to the present day.

Over time, the breadth of PER has increased dramatically. Researchers have branched out into new populations of students and new angles of study. For example, cognitive science has informed us about memory and learning at the most basic levels. Social interaction theory can help us understand how students work together in groups. This dissertation focuses on epistemological research, that is, research on students' views and attitudes about physics and how those views and attitudes affect their learning.

Epistemology, and Why It Matters

Research designed to assess and improve student understanding of physics concepts has been unquestionable successful. However, as one might expect, there is more to deal with in teaching than simply knowing how to engage students conceptually. In fact, the basic idea of constructivism (as generally accepted by the PER field) allows for this assumption. Students do not start out as blank slates, and come to class with a variety of prior knowledge and expectations. The assumption of prior knowledge works its way into much of the conceptual research. However, as previous work shows, student expectations (Redish, et al. 1998) and epistemology (Hammer & Elby 2002) affect how they learn. *Epistemology*, for the purposes of this dissertation, refers to student beliefs about the nature of physics knowledge and learning. This is narrower in context than the strict philosophical definition (Steup 2007), that is, of epistemology as encompassing the distinctions between knowledge, truth, and belief.

I need not wade neck-deep in philosophical jargon to understand why epistemology matters for a physics learner. If a student believes that knowledge in physics should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict. Likewise, if a student comes in thinking that physics consists of a bunch of equations to be memorized, and the instructor focuses more on concepts, there is conflict. Finally, if a student is being presented material in a fragmented way, but he or she would expect or believe the material should fit together more cohesively, that would cause another type of conflict. These conflicts (or, conversely, a lack of these conflicts) can affect learning above and beyond specific difficulties with mathematics or concepts. That is why epistemology matters.

Assessing Epistemology

Scholars in educational psychology have been assessing student epistemologies for some time, and a detailed description of their efforts will come in the next chapter. The main difference between those studies and this one is that many tended to assess general beliefs about knowledge and learning independent of a specific class. Those who focused on physics did not use similar video and interview triangulation, which is a key methodological difference. Also, recent research emphasizes distinctions (Hogan 1999) between *public* and *private* epistemology, that is, beliefs about how one learns best for his or herself and beliefs about how others in specific fields likely learn things. Because previous science epistemology studies often ask general questions about what “scientists” do, they might not say a lot about how specific students behave in their own personal learning contexts. Also, the lack of learner-specific epistemological results cannot help us deal with epistemological blocks or conflicts when we find them.

Since we care so much about student epistemologies as they relate to physics, we must develop ways of assessing them within the context of physics classrooms. This dissertation will discuss a number of ways the scientific community has come up with to “measure” epistemology and epistemological change for a variety of population sizes. To preview, an expected tradeoff exists between richness of data and ease of use. We can learn a lot from each of these methods, but the nuts and bolts distinguishing them will be the point of subsequent chapters.

The “reformed” class context at Maryland

I will refer to classes conducted at the University of Maryland throughout this work using the adjective “reformed” or otherwise referring to PER influence. All the Maryland courses discussed are algebra-based introductory courses that fulfill minimum physics requirements for premed students, biology majors, and many others. A recent article (Redish & Hammer 2009) discusses the pedagogical structure used in the reformed course. The common thread in all PER reforms is a focus on actively engaging students. Traditional recitations at Maryland involve review lectures from teaching assistants or simple question and answer sessions based on homework. My group’s reformed sections use recitation time to have students work in groups on tutorials with TAs there to facilitate – even if it means not helping directly! Tutorials are conceptual worksheets done in the style of McDermott and Shaffer (2002) but written locally to focus on epistemological issues.

The worksheets (see a sample in Appendix E) contained explicit moments where students were asked to reflect on the purpose of the learning activities. The example in the appendix discusses the collision between a heavy truck and a light car. Students correctly notice the lighter vehicle reacts more, but incorrectly infer that the truck exerts more force. The refinement comes when they realize that more reaction means more acceleration. After all that, they are asked to summarize everything they have learned conceptually. Finally, they are asked, “What general strategies are suggested by this tutorial—strategies you might be able to use with counterintuitive concepts appearing later in the course?” This reflection question is called “the most important question in this tutorial.”

Course reforms were not limited to tutorials. Lectures frequently focused on reconciling common sense with difficult conceptual ideas, and demonstrations were done in the style of interactive lecture demonstrations (Sokoloff & Thornton 1997). The professors and TAs organized students into groups during out-of-class office hours as well. A major point of all of this was to foster not only conceptual development but epistemological development, which the surveys discussed in this dissertation are designed to assess.

Epistemological surveys

As with conceptual issues (Hestenes, et al. 1992 and Thornton & Sokoloff 1998), researchers are interested in developing epistemological surveys for large lecture classes. Why do this? Many curricular and instructional changes in PER are applied to large classes, and surveys help us evaluate the effectiveness of those changes.

The University of Maryland PER group has worked on some epistemologically-relevant survey instruments in the past (again, Chapters 2 and 3 will discuss these in greater depth). Redish, Saul, and Steinberg developed the Maryland Physics Expectations Survey (MPEX), which is a 34-item, Likert-scale instrument that probes student expectations about physics. Although the survey name implies a focus on expectations, there is epistemology that is unavoidably tangled in the results. White, et al. (1999) created an instrument called the Epistemological Beliefs Assessment for Physical Science (EBAPS) that is more focused on strictly epistemological issues. Elements of both the MPEX and EBAPS were used in creating a new version of MPEX called the MPEX2. The MPEX2 is the subject of Chapter 3. In short, it is a survey designed to evaluate courses by asking students questions relating to their views on knowledge coherence, learning independence, and the relationship of concepts and equations in their physics course.

Assessing epistemology with a survey does not require a novel set of questions. Chapter 4 of this dissertation will discuss how the Force Concept Inventory (FCI) (Hestenes et al. 1992), a multiple-choice conceptual survey, was modified to study epistemological issues. My concern, as also noted by Mazur (1997) was that students often learn concepts in classes but are not intuitively convinced that those concepts are true. If students do not really believe the answers they give on a conceptual survey, or they do not believe the answers they give make sense, what does a "high" conceptual understanding score truly indicate?

A common epistemological view expressed by many students in the context of a physics class is that physics knowledge is counterintuitive and incompatible with common sense. Of course, as teachers, we do not want our students thinking like that. My study took the standard FCI and changed the instructions so students have the opportunity to mark the "answer that makes the most intuitive sense to them" as well as the "answer they think a scientist would give." They had the option to put the same choice for both. This survey allowed me to examine the difference between a “traditional” physics course and one with more active engagement and emphasis on conceptual reconciliation.

Interviews

While survey methods are better for assessing the effectiveness of epistemological reforms in classes, in-depth interviews provide richer data that directly informs us about specific students. Many studies in the education research literature have developed surveys and interview protocols to tell us about epistemologies, but they fall short for my purposes in a few key ways. For one, they are often not specifically geared toward physics classes. While a student’s insight about “science” in general might help us teach him or her something in physics, the connection is not what it could be. Also, a study by Hogan (1999) makes a case that there is a distinction between student views about professional scientists’ knowledge and learning and their own knowledge and learning. Many previous studies focus on the former (or *public*) aspect, ours focuses on the latter *private* aspect.

Chapter 5 discusses my interview efforts. I interviewed two students in our introductory mechanics class, and Chapter 5 discusses one of them in detail. I videotaped their groups’ discussion of tutorial worksheets. After each week, I interviewed the students about specific moments from the video. Because the tutorials varied in difficulty throughout the semester, it is difficult to tell a story of their epistemological development, but evidence of important epistemological truths popped up consistently over the weeks.

One student was often able to reconcile common sense with the material, but those reconciliations did not stick because she saw reconciliation as a linguistic issue, that is, she thought common sense and physics disagreed because of differences in the meanings of words. I focus on her story in Chapter 5. My other student was mathematically capable, and also able to reconcile, but his difficulties came about because there was a disconnect for him between common sense and physics. For him, once an equation is derived, one can use it without thinking about it in the "old way" again.

The goal from here

This study will address the following research questions: (1) What factors can affect how and whether a class succeeds at fostering epistemological change? (2) How can the combination of classroom video and interviews give us fine-grained information about a student's epistemology as opposed to broad characterizations? (3) Can a survey aimed at the specific issue of reconciliation see epistemological differences that a broader instrument misses? (4) What can triangulating interviews and video do for studying epistemology that one method alone cannot? I will also place where this work fits within currently held ontological and methodological frameworks in the literature.

Beyond the literature review in the next chapter, the rest of the dissertation will discuss the methods of learning about student epistemologies I have outlined above. In each methodological chapter, I will discuss the motivation for studying epistemology in that way, the way I developed my instrument or method, and some results from each method. I will also address concerns about reliability, validity, and applicability.

As one would expect, applicability, validity, and data richness vary from method to method. For the MPEX2 and FCI survey methods, the instruments are easy to distribute and get results from. They also require a minimal time commitment, and provide a reasonable picture of a large group of students. However, individual student results are less reliable, and responses to specific questions are less meaningful. In contrast, my case studies taught me specific things about my two students one could not have learned from a simple survey. The time required to watch video and do the interviews makes doing it for more than a few students prohibitive.

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Chapter 2: Methods and theoretical assumptions from previous epistemological research

Introduction

The purview of "epistemology" in this dissertation

Since this dissertation is concerned with epistemological issues, it will help to clarify what is meant by "epistemology." In the strictest philosophical sense, epistemology refers to the study of knowledge and justified belief (Steup, 2007). This domain includes the source, limitations, and justification of knowledge. "Epistemology" is used in the title of this dissertation in a slightly different sense. My title refers to specific knowledge or beliefs a person *has* or *can develop* about "knowledge and justified belief," especially in science.

What does this mean? A student will possess ideas (whether explicit or tacit) about what constitutes "knowing," how learning is achieved, and what scientific knowledge is all about whether or not he or she has been reflective about these ideas. No matter the form these ideas and beliefs take, they will be influential with respect to the understanding of science (or lack thereof) that follows. When I refer to a student's "epistemology" as a noun, I am referring to their beliefs about knowledge and learning. The form this knowledge takes is a point one can argue, and I will discuss those possible forms in future sections. Also, as we will see, many papers in the literature are not subject-specific with respect to epistemology, though some refer specifically to science or physics. My work exists entirely within a physics context.

Structure of the review

This review will start by reviewing some phenomenological artifacts of epistemology previously discovered in the literature. The work here will discuss sample interview questions and responses, categorization schemes, and conclusions from Perry (1970), Belenky, et al. (1986), King and Kitchener (1994 and 2004), Deanna Kuhn (1991), and Schommer (1990). In doing this, I hope to communicate a sense of how these authors noticed behaviors in students and interpreted their data. For each author, I will list some questions they asked and examples of student answers that led to different categories of student and epistemological interpretations.

Next, I will review some of the methods used previously to interpret epistemological results. My work borrows from all of these methodologically if not theoretically. First, I will be discussing interview-based methods. These methods are used to study individual students and identify interesting epistemological properties one could look for in other students. Next, I will discuss survey methods. These are usually administrable to large numbers of students, but are as likely to be used for evaluating whole classes. Often, factor analysis is used to infer information about dimensions that are either discovered on the spot or hypothesized in advance. I hope to show that for both survey and interview methods discussed here, the goal is ultimately to place students into categories. Students are sorted according to their place in a scheme of categories, and occasionally only one epistemological context is used to label students as sophisticated or unsophisticated using these categories.

My discussion of the definition of the term "epistemology" can leave one wondering exactly what type of thing or *ontology* these beliefs can have. Ontology is often taken to mean a theory about the nature of being, but here I use it to describe what kind of thing a conceptual or epistemological belief is. Ontologies can take several forms that differ in small details, but the key way to distinguish them is to describe them as either unitary or fragmented. An example of an epistemological statement with a unitary ontological influence would be: "Student B holds the belief that knowledge must come from authority." All of the references cited so far in this section take unitary views. A more fragmented ontological manifestation might look like: "Student B has activated a belief in one specific context that knowledge most productively comes from authority. Other contexts may activate completely contrary pieces of evidence." A researcher's view on what form these beliefs take will affect the way he designs his research methods and interprets the results in the form of both explicit and tacit assumptions that underlie the work. Once I finish discussing the phenomenological and methodological aspects of the epistemology literature mentioned above, I will be able to discuss that work in ontological terms.

The final section will look at epistemology research in physics specifically, which is the domain of this dissertation. In examining the field as it applies to physics, I hope to see whether physics education researchers use similar methods and interpretational schemes. Part of this examination involves studying mixed methods that inform the case study work I present in Chapter 5. The previous work I build on most combines video observation with interviews to produce insights that neither method could have performed alone. Sandoval (2005) puts forth a "challenge" for an epistemological research program that I will respond to at the end of the review.

Phenomena in epistemological research literature: Perry

Perry's interview method

Perry (1970) began his work in the 1950s with the goal of documenting the experience of Harvard students during their years of college. He and his colleagues used the Checklist of Educational Values (CLEV) (studied in Perry, 1968) to draw an initial pool of subjects (Perry's work included a small number of women from Radcliffe, but their input was not used in developing his scheme). The CLEV consists of agree/disagree items such as "the best things about science courses is that most problems have only one right answer," "If teachers would stick more to the facts and do less theorizing one could get more out of their classes," and "Educators should know by now which is the best method, lecture or small discussion groups." The former of these questions is similar to an item used on the MPEX2 (discussed in chapter 3), but it is more interesting to note that Perry's stage scheme artifacts primarily came not from the CLEV, but from open-ended follow-up interviews. Perry and colleagues solicited volunteers from a subset of the original CLEV administration formed by looking for a variety of survey responses. Though the open-ended interviews resulted in a set of interview responses and student-invented contexts that varied greatly, they were still able to notice a developmental pattern from their first sample. The selection of a larger second sample ignored the students' CLEV results altogether. That second sample was used to confirm and refine their developmental findings from the first sample.

Perry made it clear to subjects that they would be discussing their college experiences. However, Perry's goal was for the subjects to describe their experience in their own terms. Therefore, his interviewers had to keep the interviews as open as possible. Although the students may have had some impression as to the interests of the researchers from the CLEV or other introductory instrument, the judgment of Perry's interviewers was that these impressions were diverse and did not have large or long-lasting effects in the interviews. Still, it is reasonable for an interviewee to expect that the researcher knows what he or she wants to know and will therefore provide at the very least a takeoff point for discussion. Since this did not happen in Perry's interviews, it caused social tension which had to be explicitly discussed. When students would ask for more specific questions, the interviewer would have to indicate that any response besides refusal would presume some guess as to what would be relevant for them. The awkwardness would need to be something the interviewer and subject face together.

Early versions of Perry's questions that were not effective included "What do you think has influenced you most during the year?" or "Do you think you have changed in any way?" Both of these imply an influence or change, though, and even that proved to be too restrictive a box for the student to place answers. The general form (inspired by work by Merton, et al, 1952) eventually settled on was the statement: "Why don't you start with whatever stands out for you about the year?" If the student ever responded with a general statement, the follow-up question would be, "As you mentioned that, were you thinking of some specific incidents, or do any examples come to mind?" The interviewer would respond specifically to the statements each student makes, and Perry claims that his relevant epistemological data comes naturally from these conversations. At the end of his interviews, the subjects are invited to comment on responses they had given on the CLEV or items that interested them.

Perry acknowledges that there is no way to guarantee that even the best-intentioned interviewers do not covertly influence the discussions that take place. His view was that a positive and caring attitude about the interviews would be more effective than a completely deadpan approach, and this seemed to play out in the way his students got used to the open-ended approach. Although there is no guarantee the no bias was introduced, the two samples (according to Perry) provided equally reliable data even though they had an idea for a developmental scheme only after the first samples' interviews were done.

An overall structure of Perry's stage scheme

Although Perry noted that student responses varied greatly in his open-ended interviews, he and his colleagues "gradually came to feel that we could detect behind the individuality of reports a common sequence of challenges to which each student addressed himself in his own particular way." This section will discuss that sequence as well as give examples from his work. A key overarching point of this analysis is that whatever the details, Perry's data analysis focused on taking data from the subject and *placing the students into categories* based on their interview responses.

Perry's scheme involves nine stages or categories for students to be placed in. He focused more on coherence within data rather than persistence of epistemological forms within a particular student. The forms (also called "structures" by his group) would be labeled, and compared to interviews from other students. The most persistent forms were ordered into the categories. Though there are nine stages, Perry further lumps these stages into three categories. The first three stages represent an absolute right-wrong view of knowledge (called *dualism*), and as development continues, room is made for the possibility of less dualistic thinking. In the middle three stages, a person realizes that knowledge has a *multiplicity* that cannot be wedged into a "right vs. wrong" scheme. He or she starts to find that *relativism* (that is, the idea that knowledge comes from judgments made about things discovered inside a "multiplicity" framework with proper attention to specific contexts) may be a valid and productive stance, yet there is still the feeling that no one can really know anything for certain, and "anything goes" since people can disagree. In the final three stages, a subject evolves personal and long-lasting commitments to relativist thinking. This is done partially by realizing attention to context removes the "anything goes" feeling prevalent in the previous positions.

Perry's first three stages: Dualism

The first position is as simple an absolutist place one can be, and Perry calls it "basic duality." Knowledge is divided cleanly into "authority/right" and "illegitimate/wrong" categories, and simple memorization or obedience to authority is enough to tell these apart. Perry notes that while some bending to authority is necessary to reach the point of attending college, most students have moved beyond this phase. Many of Perry's artifacts from this stage come from students thinking in retrospect, for example, saying something like "When I went to my first lecture, what the man said was just like God's word, you know." A different student gave a "position one" response in discussing the CLEV item "There's nothing more annoying than a question that may have more than one answer." He *disagreed* with this point early in the semester, which is not what one would think an absolutist would say, but when pressed to elaborate, he noted, “Oh! Well, when I came here I didn’t think any question could have more than one answer – so why be annoyed?” This sort of response represents the kind of false positives my group sought to avoid in its own survey work. Surveys in particular are susceptible to these false positives because false positives are often brought on by quick, decontextualized answers where the student has no chance to elaborate. This can happen in interviews as well.

The second position features students who have been exposed to multiplicity of thought but fight it. Often, the multiplicity comes in some form from an authority figure, and the student resists. The student sees attempts to branch knowledge out too much as a distraction from real learning. One student said of English professors, “they seem to like to be clever at the expense of what they’re studying at the time. They like to find a paradox, whether one really exists or not, and they’ll twist the material so they can say something ironic.” Another student who did not want to take required science classes noted that “for *some* people I suppose it does [make sense to take it], somebody who has a sort of better-rounded mind than I do, and less centered. They can’t make *me* learn it. *It’s going to do me no good!*” Though both of these students exhibit an opposition to alternative views they are being presented, Perry says this stage is one that opens the door for future epistemological development. Although it does not appear here that students are changing epistemologically at all, they are being made aware of alternatives that may come into play later. As a standalone “position,” Perry is viewing goals and expectations as indicators of epistemology. Other authors discussed later do the same thing in their schemes.

The third position is labeled “multiplicity subordinate,” where students still resist somewhat the notion of multiplicity but start admitting that it may be a true worldview in subjects and contexts they did not before. Perry gives an illuminating quote from physics:

> “I’d feel rather insecure thinking about these philosophical things all the time and not coming up with any definite answers. And definite answers are, well, they, they’re sort of my foundation point. In physics you get definite answers to a point. Beyond that point you know there *are* definite answers, but you can’t reach them.”

To this student, uncertainty is unavoidable, even in physics. Digressions from pure right/wrong thinking are not obstacles placed intentionally by authority figures, but parts of reality. However, there is still opposition students have to these parts of reality. Many students exhibiting evidence of being in this position reject the notion that professors can reward a large quantity of input or work with no objective basis in right vs. wrong thinking. One student, before complaining about the uselessness of assignments where people expound on subjective, interpretive, or uncertain things says, “This place is all full of bull.” A different one elaborates: “I found that my section man, out of two lines, could talk a whole *hour*. And at first I didn’t see where he got it all. I said, where did *that* come from?” These students see that their colleagues are graded by authority figures even on questions where there is no “right answer,” and their search for answers in playing this game will open them up to the commitments of future stages that Perry will call “relativistic.”

Perry positions 4-6: multiplicity

Perry’s fourth position represents approximately the stage he finds the largest number of incoming college freshmen at during the start of their careers. In deciding how students evolve from the third position, he found that most enter a phase where they more willingly or eagerly accept that a departure from simple dualism is the way authority figures want you to think. This is a difference from, say, position two where authority dictates more *what* (instead of *how*) they want you to think, namely, that responses given in a class might be nuanced enough to evade right/wrong categorization. One humanities student in a literature course had an epiphany that a certain way of thinking will be rewarded:

> Finally I came to realize about the middle of the second term that they were trying to get you to look at something in a complex *way* and to try to weigh more factors than one, and talk about things in a concrete manner. That is, with words that have some meaning and some relevance to the material you were studying. And all of a sudden my grade just *shot right up* and stayed right up.

This quote indicates some deference and a lack of true independent thinking, yet it lacks some of the oppositional tendencies earlier positions showed. However, Perry also noted in some students an oppositional side to this phase where the same eagerness to think a certain way doesn't exist. For this more oppositional crowd, multiplicity acts as a refuge from committing to any one answer. One student said that "that's the great thing about a book like *Moby Dick*. *Nobody* understands it!" This meant that since students and other scholars have the potential to differ, no one really "knows" anything. Still, no matter the level of opposition a student shows here, there is evidence in this position that the presence of a multiplicity of ideas allows for peer communities to form that will help in later positions of Perry.

The fifth position represents an important, potentially "revolutionary" transformation. To this point, the student has been seeing multiplicity or relativism as subordinate to dualism. By the fifth position, non-dualistic ideas are not inspired solely by authority, but intrinsically. In future positions, dualistic thinking becomes a subordinate or a special case within a relativistic framework as those commitments are developed. The transition between positions four and six can take place during a single year, though, so Perry found this position hard to get a handle on. He called this phase the most violent accommodation the student will make, yet also the quietest. They will make that transition and not know how or when it happened. In one episode where a subject did not seem to be enjoying the conversation concerning a "simple" versus a "complex" way of looking at things, he said "… you can't talk about being complex as, as a *conscious policy*. I mean it's *not* a conscious policy, it's, it's just something that's been absorbed into you." Another key feature of phases after this one is that students start to see authorities as co-"gropers" (but more experienced ones) in a relativistic world in which we all live.

Position six foresees developments occurring in the final three phases. Once a student accepts that multiplicity is a part of the world, he may become disoriented. At this point, he has a few choices. One is to throw his hands in the air and deny the need for deeper meaning in any context outside his direct experiences. Beyond those, he gives up. Another is to embrace multiplicity, but only to exploit its existence for personal opportunistic gain. Both of these are called "Escape" by Perry. The other alternative is to develop commitments to a relativistic framework, which are personal affirmations about the need for reasoned and contextual thought within an otherwise chaotic and multiplistic world. Once he realizes that reason is a helpful way of sorting through the mess but may not convince others or work out in every situation, he is in position six. One (possibly former) atheist discussing his beliefs shows the kind of personal responsibility required: "Took me quite a while to figure out… that if I was going for a universal truth or something to believe in, it had to come within me, and I don't know whether Harvard taught me that or not." Along this road, a student must make several decisions: How much effort can be made do delve into different possibilities at the expense of focusing on grades? How do career ambitions affect how one studies and thinks? How does a new sense of relativism affect personal faith? When does one commit to giving SOME opinion when it is required? However students answer these questions, here they begin a "commitment to Commitments," where the capitalized version is how Perry refers to the specific affirmations of this section.

Perry's final three stages: a commitment to relativistic thinking

Perry links the last three stages in one description. By the time a student has reached position seven, the "commitment to Commitments" has stabilized. Differentiation between these three phases is simply a matter of style and degree. In position seven, his commitments are focused toward a defining decision based on a self-identification or career choice. His relativistic commitments exist mainly within that external structure. One example of such a commitment structuring went like this:

> I've always had a lot of doctors in my family, and my father meant to be a doctor and then, ah, quit during the depression. And he'd always wanted me to be a doctor, at which I had rebelled. And well, I had a board and room job this year, taking care of kids and, well, it just came slowly to me that this is really what I want, and for the first time I had a little direction. Right now I'd like to go into pediatrics; I'm really set on this deal.

According to the definition of epistemology earlier defined in this chapter, this statement does not seem epistemological. Rather, it seems as though this student is simply becoming comfortable within his own skin. To Perry, the latter positions in the scheme reflect a growing comfort in many avenues of thought. Opposition and apprehension to certain modes of thinking do not exist here in the way they did in earlier stages.

In position eight, the external structure of the student's commitments (career or otherwise - for example, "I will be a physics teacher") loses some of its strict influence (for example, "there are lots of ways I could be a physics teacher!") Position nine was one not seen often (13 out of 120 "scorings" within twenty interviews), but was devised originally as an extrapolation: this is where you're placed if both the content and the style of your relativistic commitments become comfortable and well-developed. It is impossible (for both Perry and myself) to explain the eighth and ninth positions in a quick quote because only a deep and persistent affirmation in a lengthy context can display those specific positions in a detailed way. On the surface, a position like eight or nine may look like this:

> I've come to a fairly settled idea of what I want to do as far as my career is concerned, and also my general values have become oriented, kind of settled to some degree. Also once thing I've noticed, I've finally become at home. I feel at home in this atmosphere here, and coming from out where I do it took me quit a long time to do that.

The difference between this and earlier positions is that there used to be a great deal more discomfort stemming from the way the learning process happened (possibly from opposition to multiplicity, relativism, and the like). The acclimation process often takes several years.

Perry admits that the latter three stages do not represent changes in worldview. The difference between positions seven and nine, for example, is much smaller than the difference between positions four and six ("multiplicity" stages) or even between two and three (in the "dualism" category). More modern epistemological discussions would not notice much difference between how position seven and position nine students view the nature of knowledge. Once commitments to contextualized relativism are made, there are few other places left to go.

Though Perry also notes ways of leaving this developmental scheme, for example, “escaping” in frustration when multiplicity becomes too much to manage, the most important aspect of his scheme for my purposes is that he is trying to lump either student statements or the students themselves into three coarse-grained or nine fine-grained categories. I would not disagree with his coding approach if it simply were applied to individual student statements, as the context of those statements could be placed alongside the coding accordingly. However, in places he does speak of an “average position” for students. Many of his seniors, he would say, did make it to around positions seven or eight. Although it is hard to disagree with anyone who places so much emphasis on relativistic actions across different contexts, there was no evidence in Perry’s work that he sought to correlate how students might have scored differently within their own different contexts. Aspects of his open-ended interviews deservedly persist to today (and within my work), but it seems to be a large omission that no examples were mentioned of students being, say, dualist in science and relativist in humanities or religion. Examples of students who “score” differently in different contexts would probably pop out of his data quickly if the interviews were not focused on the (somewhat singular) context of what sticks out for students in college.

Despite my disagreements, the present work will try to take advantage of some of the benefits of a Perry-style interview. In an open-ended interview, it becomes hard sometimes to disentangle epistemological information from distracting artifacts, for example, the discussion of career or self in Perry's interviews or the discussion of conceptual difficulties in a physics-related interview. Perry's interview context elicits very authentic and honest responses that are important for any epistemological interviewer to get. When discussing later authors in this chapter, I will look for both how their schemes compare in terms of these advantages and how (or if) they treat the issue of analysis across contexts differently than Perry does.

Phenomena in epistemological research literature: Belenky, Clinchy, Goldberger, & Tarulet

Subject pool and protocols

Belenky and her three coauthors (Belenky et al. 1986 – Belenky's name is first alphabetically among four who shared the work equally) sought to understand how women drew "conclusions about truth, knowledge, and authority." Starting out as psychologists in the 1970s, they felt that both clinical psychological settings and institutes of formal education were inadequately serving women's needs. They also argued that prevailing epistemological ideas of the time were centered on male experience, and again, were insufficient for understanding the unique differences observed in women. For example, they knew of much anecdotal evidence (and supporting research) that women have more trouble than men asserting their authority, expressing themselves persuasively, and feeling unheard when they have ideas to contribute to discussions.

Belenky and colleagues accuse past modelers of intellectual development of unfairly dividing mental activity into "thinking" (which includes thought along abstract or impersonal lines) and "emotion" (personal and interpersonal thought).

The former type is considered strictly masculine and the latter strictly feminine. The authors say that prevailing thought at their time and earlier indicate that expended energy in one of these parts leads to a depletion elsewhere. Also, they assert that women in academia must counter prejudices along these lines from day one.

These authors have been influenced by Perry's work, but feel it inadequately discusses the female perspective. Perry had a small number of female subjects in his study, but none of their interviews were used to illustrate the positions in his scheme or establish their validity. Perry claims that evidence from his small female sample fits seamlessly into his scheme. Belenky et al. point out that Perry's scheme may have gaps in it where patterns of female development may differ from the men. Though these authors question the adequacy of Perry's positions for all learners, they agree with Perry that a phenomenological approach centered on interviews is the best place to start.

Perry's subject pool was entirely college students, but Belenky et al. felt it important to study women's experiences from more walks of life – from both formal and informal educational settings. Among their 135 subjects were 90 students from six diverse colleges (ranging from private liberal arts colleges to inner-city community colleges and public schools for at-risk populations) and 45 from what they call "invisible colleges" – family agencies geared toward supporting women in parenting roles. They had several reasons for tapping this pool of subjects; for example, the agencies are often run by women and are therefore untainted by the male-centered educational biases other places possess. Also, they gave the researchers a chance to understand how the role of motherhood shapes women's thinking. Many women from these agencies were from impoverished rural areas. All told, Belenky and colleagues had a much more educationally, socioeconomically, and ethnically diverse subject pool than Perry had.

Belenky's team mentioned to each subject that their group wanted to hear about "what was important about life and learning *from [the subject's] point of view*." Each subject chose the location for the interview, and each interview started with what Belenky called the "Perry question": "Looking back, what stands out for you over the past few years?" Although the interviewers were very patient and eager to allow the women to articulate as much as desired, they followed up with an extensive interview protocol. In describing this protocol below, I will focus most heavily on the epistemological aspects.

The first interview section is based around Perry's question as well as the questions "What kinds of things have been important?" and "What stays with you?" The next section is inspired by Gilligan's work (for example, Gilligan 1982). In it, subjects are asked to describe themselves and reflect on how they think they have changed over time. Next, the subjects are asked to discuss what it means to them to be a woman and what differences they perceive between men and women. The fourth interview section contains three blocks of questions about relationships: (1) concerning what relationships are important to the subject and why, (2) what relationships exist between subject and parents, and (3) has sexual abuse happened to the subject. Following this section, subjects are asked about a real life moral dilemma they have faced (this was, again, inspired by Gilligan). After that, the subjects answer questions about their educational experience. A sample epistemological question from this section is “In your learning here, have you come across an idea that made you see things differently… or think about things differently?”

The seventh interview section is borrowed from heavily in the case studies of Chapter 6. The questions concern women’s views on expertise, resolving disagreements, and establishing truth. The following questions are posed to the subjects who are in school or recently attended college:

- In learning about something you really want to know, can you rely on experts?
- How do you know someone is an expert?
- What do you do when experts disagree?
- If experts disagree on something today, do you think that someday they will come to some agreement? Why or why not?
- How do you know what is right/true?
- Do you agree with this person who says that where there are no right answers anybody’s opinion is as good as another’s?
- Can you think of an opinion that you think is wrong?

Four follow-up questions touch on these same issues in specific context (for example, evaluating a book or movie). The last two questions listed above especially seem to touch on ideas from Perry. They are probing around the area Perry would call multiplicity.

The final two sections contain a constructed moral dilemma and a conclusion where the subjects have the opportunity to suggest questions and predict what their future holds. Though Perry is clearly an inspiration to these researchers, they have a much more structured interview protocol touching on a wider range of prepared questions. In the section that follows, I will discuss the stages (called “ways of knowing”) Belenky and her colleagues observed in their subjects’ interview data. Where appropriate, I will draw parallels to Perry’s three major stages (dualism, multiplicity, relativism) and illustrate places where they found differences between their female populations and Perry's largely male populations.

"Ways of knowing" as described by Belenky et al.: dualist views

The first position of dualism described by Perry was a simple, authority-accepting view that very few subjects held at the time of their interviews. Many subjects discussed this position in retrospect. Similarly, Belenky and her colleagues call their first way of knowing a stage of "silence" that they only observed in two or three subjects. In the silence position, the women in question lack their own voices and are completely dependent on external authorities for direction. This aligns with Perry's early positions, which were also heavily influenced by the force of authority. Women in this position are often socially or educationally disadvantaged, so the contexts in which they reveal this position reflect great personal troubles. For example, subjects would say things like the following:

- "I don't like talking to my husband. If I were to say no, he might hit me."
- "I had to get drunk so I could tell people off."
- "The baby listens to him. Men have deep voices. But me, I can't do anything with him."

Silent women see authorities as all-powerful, and obedience to these authorities is essential for getting by in life. The above statements may not be epistemological, but many women in Belenky's silence stage may have been pushed by fear to doubt their ability to speak for themselves. Authority makes a difference in religious and social interactions also, ("We, in our religion, don't believe in abortion.") as well as in women accepting gender roles ("I was brought up thinking a woman was supposed to be very feminine and sit back and let the man do all the stuff."). Belenky and her coauthors go as far to say that women feel "deaf and dumb," and they feel that way as a result of being isolated, demeaned, or otherwise treated unfairly by outside influences. In their next documented "way of knowing," the women in the study are still epistemologically dualists, but without as many of the mental and vocal restrictions.

Women can exit the silent stage in a number of ways, but one way of getting out that is unique to them is through childbirth. Many women in the silent stage find out of necessity that they need to see themselves as less dependent on others and more capable of thinking and speaking for themselves. Unlike the "deaf and dumb" from the previous phase, women set in the second "way of knowing" (called *received knowledge*) open their ears to the outside world and begin to think of themselves as learners. They still see knowledge as something transmitted from knowledgeable sources, though. For example, one college student said "I enjoy listening to discussions. I find I am doing okay just through listening." Those with a greater level of knowledge are still viewed reverentially, but from the perspective of a listener this time. One woman from a family learning center reflected thusly:

> "I have to rely on the experts. I've never been one to make decisions. Whenever I need to know about something, I have to go to someone who knows. I have to rely on them because I don't know anywhere else."

In earlier times, however, this woman felt that authorities must *show* things to her or *do* them directly. Though the dependency on experts is still present, she at least feels now that authorities can at least *tell* her what to do now. In comparing their subjects with Perry's, Belenky et al. note here that the women are just as awed by authority figures as Perry's, but they indentify with them less. Women who get their knowledge by considering the "voices of others" rely on outside sources for both knowledge about the world and knowledge about self. For example, one subject noted, “I don’t think I’m in control. I’m very easily influenced by either side. My counselor told me something, and I’m very influenced by it. A friend may say something else, and I’m influenced by that!” Only by forming a voice for themselves will such a person be able to move forward in their development.

“Ways of knowing” as described by Belenky et al.: multiplicity-like views

The third step in the scheme of Belenky et al. involves to them a large shift in thinking. Called “subjective knowledge,” this way of knowing represents the first time women use an internalized voice to sort out truth from falsehood. The most poignant example of this stage came from a woman named “Inez” who had been belittled and abused by her father, brothers, and husband. Therefore, she lived much of her life knowing through “silence,” and this did not change until she learned at twenty-five that her father had been convicted as a child molester. Something clicked inside; Inez realized she would have to walk away from the past. It helped when, as she described it, she discovered a part of herself “I didn’t even know I had – intuition, instinct, what I call my gut.” Belenky and colleagues say that about half their subjects fit in this subjectivist stage, and many were forced into this upon failure or betrayal by (usually male) authority figures. Like previous stages, motherhood encouraged this way of knowing for many women. An older woman who needed help supporting her children noted, “I wrote to a priest that I was very fond of and I asked him, ‘What do I do to make things right?’ He had no answers. This time it dawned on me that I was not going to get the answers from anybody. I would have to find them myself.” In all these cases, necessity of some type forced the change to this way of knowing. Although in a sense the "subjective" way of knowing is still somewhat dualist in that there is a definite right and wrong to distinguish between, the added voice of reason provides a noticeable epistemological leap. Belenky et al. say that their "subjectivism" emphasizes a "reliance on personal truth" in exactly the way Perry's "multiplicity" position does, and therefore the terms are normally interchangeable. For them, the term "subjectivism" is "a more apt description of women's experience of inner knowing" than Perry's term. However, in my discussion, I will equate the two as similar as they often do.

In the "subjective knowledge" position, other important epistemological artifacts unique to women appear. The inner voice that Belenky and colleagues mention is described as a "small voice" that one "just knows." The source, then, is quite vague. While articulating this point, one subject noted, "It's like a certain feeling that you have inside you. It's like someone could say something to you and you have a feeling. I don't know if it's like a jerk or something inside you. It's hard to explain." Also, and more importantly for this dissertation's field, women who adopt subjectivism begin to distrust or reject abstraction, logic, and even science. Evidence for this comes in sound bites like "What's missing in science is a whole sort of human element" and "I don't think we need scientific methods to ascertain what's right at all. I think we need internal exploration and knowledge of self to know what's right and what's true." Future epistemological studies of women in science courses could bear on whether this scientific resistance exists, but perhaps resistance would be more noticeable in women who avoid science classes and scientific fields intentionally.

Belenky et al. go beyond epistemological observations as they continue their description of the "subjective knowledge" way of knowing. For women in this position, they adjust their self-concept and relationships with others. This is reminiscent of when Perry's subjects (around position seven – post-multiplicity) began doing this sort of thing seriously. The researchers here notice that over half the subjectivist women took drastic steps toward becoming more independent people who were not as beholden to lovers, husbands, or other family obligations. Some even became antagonistic toward men, saying things like, "I deal with men when I have to, when I can't avoid it … I am just eager to get it over with," and "I find I can do better without men." In thinking about all this, though, the women in the subjective mode are not as secure with their sense of self as Perry's "high position" subjects were. These women are in a state of flux, for example, one said, "I'm only the person that I am at this moment. Tomorrow I'm somebody different, and the day after that I'm somebody different."

"Ways of knowing" as described by Belenky et al.: relativism

In Perry's work, the way people sorted things out epistemologically was by using their inner "voice of reason" to sort through the mess of multiplicity. In this way, Perry's subjects became relativist. Belenky's women undergo a similar transition where the "inner voice" from the "subjective knowledge" way of knowing evolves into a reasoning tool, and this way of knowing is termed "procedural knowledge." Many inner voices begin acting in this role when previous ways of looking at the world are challenged by outside (sometimes authority) figures. The transformation, as Belenky et al. describe it, starts out when the inner voice becomes more measured and muted. The authors attach themselves to phrases like “look closely and intensely,” “be thorough,” and “really look” when describing how the thinking process goes. Previous subjective knowers had a less careful and louder inner voice. Also, an important feature of the procedural knowledge position is that emphasis is placed on being able to see different perspectives. This stance is epistemological; it states that to best understand and learn new things, one must approach them from as many possible angles as possible and sort through them as objectively as possible. Whether the subject is a “separate knower” who looks at alternate perspectives because it (like Perry says) is something “They want you to do” or a “connected knower” that internalizes different ways of looking at things, women in the “procedural knowledge” position begin to make judgments between these alternative perspectives.

Belenky and colleagues discuss “separate” and “connected” knowers as both being in the procedural knowledge phase. The separate knowers are equated to males in a similar epistemological place. Most of Belenky’s separate knowers were from elite liberal arts schools (often women’s colleges), and picked up methods of critical thinking from experts at those places. At the center of their skill set is a tendency to critically doubt ideas from themselves and peers, but they have to be prodded to use that skill when pitted against an authority during the learning process. Her connected knowers, which were much more common, tended to believe new things rather than doubt them. The critical thinking process for them comes about in the form of non-judgmental conversations where personal perspectives are shared and integrated into the whole experience. This is called “procedural” even though the procedures used here are not as strict as those used by the separate knowers. Belenky et al. note that women more commonly use the connected approach, and they hypothesize (but do not support with data) that they do so more comfortably than many men.

In describing the ways of knowing already described, Belenky and her coauthors noted that "external voices" are used in the "silence" and "received knowledge" positions in an authoritative sense and in the "procedural knowledge" position as entities one reflects on. In contrast, the "subjective knowledge" position requires a loud inner voice to assert itself. To move on from these positions, the authors claim, a woman must find a new voice that integrates the confidence of the subjective voice with the reflectiveness of the procedural voice. One subject put it thusly:

> "I have come to see things in my own way. I feel that everyone has something unique to say, but some people know how to develop it. Some people can go even further – they can go outside the given frames of reference."

This snippet is evidence that this person believes everyday human beings can be engaged in the construction of knowledge. To do this, one must "move outside the given" (whether the given is a piece of knowledge or a way of acquiring knowledge) and construct her own way of knowing. One surprising quote from this position was given by a humanities graduate named "Elizabeth," who said, "Science is a moral art, dictated by the human heart and the human mind. It was subjective and is subjective. Science is a creative evaluation of facts, of demonstratable [*sic*] happenings." This is striking because for many, especially those Perry or Belenky would say are in more primitive positions, science is an objective discipline based on the writings of authority. A student who can see science as an *evaluation* of facts has shown the ability to integrate both internal/personal and external/authoritative voices.

I use the term constructivist to refer to people who believe that they can engage in the process of constructing knowledge and see that engagement as valuable. In Perry's view, constructivism is a relativist position. Women who are constructivists "appreciate expertise but back away from designating anyone an 'expert' without qualifying themselves." One noted that an expert is "somebody whose answers reflect the complexity I know the situation holds." Constructivists are challenged and excited by conflict between experts, because they become "passionate knowers" that seek to stretch the boundaries of their knowledge. The passion or caring that Belenky et al. note in their constructivists helps make them better learners. One subject articulated this view:

> "I seemed to learn new ways of attending to the natural world and to people, especially children. This kind of attending was intimately concerned with caring; because I cared I reread slowly, then I found myself watching more carefully, listening with patience, absorbed by gestures, moods, and thoughts. The more I attended, the more deeply I cared."

The direction in which the caring takes them, however, differs from how Perry's male subjects moved onward once they made commitments to relativism. Belenky et al. see stages seven through nine of Perry's scheme as being where the men focused on a single self-defining act, usually a career choice. In contrast, the constructivist women in *Women's Ways of Knowing* foresee multiple commitments (academic and otherwise) that will shape their lives. I do not believe they are implying men do not care about a balance between career, family, relationships, etc., but Belenky et al. make a particular point of saying that constructivist women care as much about constructing a meaningful life as they do about any bit of knowledge or a career.

Discussion

Belenky et al. strive to fill a niche in the research literature that Perry did not: including women in interview-based epistemological development studies. This led to a few salient differences between the two books. For one, the "silence" way of knowing takes us to a place Perry's simple dualism cannot; the fact that some women are disadvantaged in particular ways leads to that stage. Also, the contexts Belenky's subjects discuss are unique to women, particularly that of motherhood. The protocol outside the "Perry questions" is much more rigid and not as open to subject-generated issues. A set of the interview questions may prime the women to discuss gender-specific behavior more than they may have naturally done so. For example, the section on relationship questions included prompts such as "Have you had a really important relationship where you were responsible for taking care of another person?" and "Studies have shown that a large percentage of women have been victims of sexual abuse. Has this ever happened to you?" However, there are more similarities between the methodologies and stages discussed than differences. Both Perry and Belenky foreshadow future positions when discussing more primitive ones. Perry might say that students foresee or begin to accept the possibility of something like multiplicity before they embrace it and use it. Belenky noted that women must develop and cultivate an inner voice in early ways of knowing before learning how to use it as a tool in relativistic thinking. These two works also share something they *do not* do: neither discusses examples where a person might be relativist in one context and dualist in other contexts. Although both document ways in which their subjects can change from one position to another, they imply that huge personal transformations happen to people as they move forward between the positions. Such huge transformations do not seem to allow for contextual subtlety. For both Perry and Belenky, an epistemological position seems to be as much a place in life as a way of looking at knowledge and the world, so as structures they are fairly robust.

Phenomena in the epistemological research literature: King & Kitchener and Baxter Magolda

King and Kitchener's Reflective Judgment Model

King and Kitchener (1994 and 2004) have worked for decades on their epistemological construct: the reflective judgment model (RJM). Reflective judgments were first defined by Dewey (1933), who argued "[they] are initiated when an individual recognizes that there is controversy or doubt about a problem that cannot be answered by formal logic alone, and involve careful consideration of one's beliefs in light of supporting evidence" (King and Kitchener 2004). The RJM "describes the development of complex reasoning in late adolescents and adults, and how the epistemological assumptions people hold are related to the way they make judgments about controversial (ill-structured) issues." To get at this, King and Kitchener designed an interview called the Reflective Judgment Interview (RJI) used to test the students' judgment processes. The ill-structured problems were centered on the issues of creation and evolution, the accuracy of news reporting, the building of the Egyptian pyramids, and the safety of artificial food additives. In a follow-up longitudinal study, a fifth question on the safety of nuclear power was added. Aside from the ill-structured questions, probe questions are asked about the basis of their point of view, the certainty with which they hold their view, whether different opinions on the topics are right or wrong or better or worse, and how experts disagree. The interviews are scored by trained and certified raters. An important point about the scoring is that raters can record three different stage scores for each dilemma, and no assumption is made that there will be internal consistency across the dilemmas. For each dilemma and each student, scorers noticed that responses usually straddled two stages; of these, the more frequently noticed one was labeled "dominant" and the other "subdominant."

King and Kitchener noted seven stages in their model, divided into three major groups. The first major group consists of the *prereflective thinking* stages. Subjects in stage one see knowledge as existing absolutely and concretely. Also, there is no need for justification of beliefs, because belief and truth correspond perfectly. Their sample quote from this stage was "I know what I have seen." In stage two, knowledge is just as certain but not always immediately available. In addition to the senses supplying knowledge, authorities may also supply it, for example, in the quote "If it is on the news, it has to be true." Stage three introduces the possibility of uncertainty in knowledge. If it is uncertain, all one can have is personal belief or opinion until an authority obtains absolute knowledge. One subject put it this way: "When there is evidence that people can give to convince everybody one way or another, then it will be knowledge; until then, it is just a guess." This group of stages corresponds with Perry's dualism positions: there is only absolute right or wrong, and only toward the end of this set of stages can one see a glimmer of what Perry would call multiplicity.

The second group of two stages consists of what King and Kitchener call *quasireflective thinking*. Stage four subjects believe that knowledge is uncertain and the arguments and evidence a person can give can depend on pre-established beliefs. Therefore, much of knowledge is ambiguous. Regarding some of King and Kitchener's ill-formed problems, one subject said, "I would be more inclined to believe evolution if they had proof. It is just like the pyramids: I do not think we will ever know. Who are you going to ask? No one was there." By stage five, King & Kitchener saw responses saying that knowledge might be contextual and subjective. The only things that can be considered known are interpretations of evidence. Beliefs exist as separate entities here, and they are justified within a specific context using interpretations of evidence. A sample subject utterance in this stage was, "People think differently and so they attack the problem differently. Other theories could be as true as my own, but based on different evidence." These two stages correspond best to Perry's multiplicity positions: the places where multiple answers could be equally valid and there is no way of distinguishing between the interpretations of others.

King and Kitchener's third group of stages correspond best with Perry's "relativism" stages or Belenky's "constructed knowledge" stages. As they put it, stage six consists of a view of knowledge where it is "constructed into individual conclusions about ill-structured problems on the basis of information from a variety of sources." Thinkers evaluate these sources based on weighting the evidence and considering different contexts. One respondent in this stage noted "degrees of sureness." This way of thinking continues more precisely in the seventh stage, where a conclusion “represent[s] the most complete, plausible, or compelling understanding of an issue on the basis of the available evidence.” King and Kitchener’s sample quote could not have been designed better by a rater: “One can judge an argument by how well thought out the positions are, what kinds of reasoning and evidence are used to support it, and how consistent the way one argues on this topic is as compared with how one argues on other topics.” Whether this person is learning to “integrate voices” as Belenky suggests or is “committing to relativism” as Perry calls it, we have reached a peak.

Baxter Magolda’s model

Another similar model was put forth by Baxter Magolda. She (1985 with Porterfield and 1987) created the written Measure of Epistemological Reflection (MER) to devise her model. The instrument and model were modified slightly in later papers (Baxter Magolda 2001 and 2004). She gave her students open-ended interviews and the MER over a five year period. A methodological difference from Perry and Belenky is that Baxter Magolda studied both genders equally, but only at one college. She started out coding exactly as Perry and Belenky did, but then decided to focus more on, as Hofer and Pintrich (1997) put it, “the nature of learning as situated in the college classroom context” rather than about views on knowledge itself.

However, what came from this study looked like prior schemes. Baxter Magolda’s model consists of four “ways of knowing” called *absolute*, *transitional*, *independent*, and *contextual*. Like other schemes I have discussed, the first way of knowing here represents an absolute right-wrong dualism and the final way listed involves judging information and multiple perspectives in context to construct knowledge. The middle stages are similar to Perry's multiplicity stages. To distinguish between them, one can use an analogy to Belenky: *independent* knowers have mastered some use of what she calls the "inner voice." Finally, *contextual* knowers, like students in Perry's advanced stages, have committed to constructing their own perspectives by evaluating multiple sources of evidence in context. Baxter Magolda also studied gender differences, and although she noted that genders tend to think along different patterns, any pattern can be found in any gender.

In summary, the work of Perry, Belenky et al., King and Kitchener, and Baxter Magolda share similarities in structure. All feature developmental stages, and all feature a dualism view (dependent on authority) transitioning to a multiplicity view (where multiple knowledge sources are accepted but distinguishing between them is difficult) to a commitment to reasoned relativistic judgments. Kuhn (1991) is another example of such a scheme. Now, I will discuss some dissenting voices. In my next subsection, I will discuss how Schommer (1990 and 2004 as Schommer-Aikins) formed her own model, which differs from the stage-like schemes mentioned up to this point.

Schommer's departure from epistemological stage theories

Schommer provided an important point of departure from the previous models. One point is ontological, and I will discuss that in the next section; basically she sees epistemologies in terms of independent beliefs rather than unitary stages. For now, though, I will discuss her idea of epistemological axes. To get an idea of what those are, note that the previously mentioned authors (Perry, Belenky et al., Baxter Magolda, and King and Kitchener) provided their own takes on a linear development scheme where subjects transition from a dualist state to a relativist one. Schommer proposed a hypothesis for an epistemological belief system made up of five independent dimensions: the *structure*, *certainty*, and *source of knowledge* (inspired by the CLEV instrument in Perry 1968), the *control* of knowledge acquisition, and the *speed* of knowledge acquisition (Dweck & Liggett 1988 and Schoenfeld 1983 and 1985).

Dweck & Liggett's work (1988) is connected to the "control of knowledge" variable through their theories about student motivation. Their conclusion was that behavior patterns in students are connected to three things: their theory of intelligence, goal orientation, and perceived present ability. The two basic theories of intelligence Dweck and Liggett distinguish between are "incremental" and "entity" theories. Children who favor an incremental theory of intelligence believe that "intelligence is a malleable, increasable, controllable quality." Those who favor the "entity" theory believe intelligence is fixed and uncontrollable. These two theories are what Schommer tries to distinguish between. Possible goal orientations include "performance," where the student only cares about positive and negative judgments they receive, and "learning," where they care most about gaining competence. Dweck's levels of perceived ability are simply labeled high or low. These three facets combine to form a behavior pattern they term either "mastery oriented" (meaning the student persistently seeks challenges) or "helpless" (the student avoids challenges).

Schoenfeld's earlier paper and book (1983 and 1985, respectively) are listed as references inspiring Schommer's "speed of knowledge" variable. In those papers, Schoenfeld discusses how student cognitive data should be analyzed to determine how students form strategies and heuristics for problem solving. A more immediate example of how Schoenfeld studies the speed of knowledge variable is in his 1989 paper. In it, he studied high school students' beliefs about mathematics homework problems. He gave a questionnaire to 206 students and asked them "how long it should take to solve a typical homework problem" (Schoenfeld 1989). The average response was under two minutes, and no one gave an answer above five minutes. He reported students saying they would give up if they could not answer a question in three to four minutes, and others saying that 10-15 minutes is the maximum reasonable time to work on "impossible" problems. His summary of these results was that students believe problems are either solvable quickly or not at all. The next paragraph shows ways Schommer probed the belief, identified by Schoenfeld, that learning happens quickly or not at all.

These five dimensions each have extremes much like Perry's scheme has dualist and relativist extremes. *Structure of knowledge* extremes would be epitomized by statements such as "knowledge exists in isolated, unambiguous pieces" to "knowledge exists as a coherent whole." A specific agree-disagree item from the questionnaire probing this axis is "Most words have one clear meaning." The *certainty* axis deals with whether knowledge is certain or tentative, and it also includes probes about ambiguity. Sample agree-disagree items include "I don't like movies that don't have an ending" and "Scientists can ultimately get to the truth."

The *source* axis distinguishes between whether one believes knowledge comes from authority or not. "How much a student gets out of school depends on the quality of the teacher" probes this axis. *Control of knowledge acquisition,* as Schommer puts it, is a factor that determines if people see ability as being fixed. Items that probe this axis include "The really smart students don't have to work hard to do well in school" and "An expert is someone who has a special gift in some area." *Speed of knowledge acquisition* beliefs range from statements like "learning happens quickly or not at all" to "learning happens gradually." The statements that probe this dimension include "Successful students learn things quickly" and "If a person tries too hard to understand a problem, they will most likely just end up being confused."

Unlike previous authors who used a mix of surveys and lengthy interviews, Schommer primarily used surveys. She developed a set of 63 short statements that subjects rated on a 1 (strongly disagree) to 5 (strongly agree) Likert scale. Some of these items came from Perry's CLEV, and others came from ideas in the Dweck and Schoenfeld articles mentioned above. These were then presorted into twelve subsets and the student scores on those subsets were fed into a factor analysis. Factor analysis is a procedure using linear algebra in which a large number of observed variables (in this case, the twelve subsets of questions Schommer and colleagues divided her survey into) are condensed into a smaller number of unobserved variables that are inferred as a result of correlations among the answers given to different items. Mathematically, the new variables are written as unit length eigenvectors where observed variables that dominate, that is, have large presences in the eigenvectors, are said to "load" together. In Schommer's study, a student's epistemological status is then no longer discussed in terms of twelve question subsets, but as a linear combination of abstract factors. There was a minimum eigenvalue criterion in place ($\lambda > 1$), and ultimately, four eigenvectors emerged from the analysis. These four accounted for 55.2% of the statistical variances Schommer noticed. They were given names corresponding to the question subsets that were represented the most in each. The names used roughly correspond with some of the five original categories discussed above: "fixed ability," "quick learning," "simple knowledge," and "certain knowledge." While the original categories may indeed account for what Schommer saw statistically, those categories did not all survive the factor modeling process, so we are left with a subset: no new cluster covers the "source of knowledge" category.

In a follow-up study similar to a study by Songer and Linn (1991) where they tried to correlate student views on science with their understanding of thermodynamics (Schommer, Crouse, & Rhodes, 1992), Schommer tried to accomplish two things: (1) reproduce the four factors she found in her 1990 paper and (2) correlate the already-extracted "simple knowledge" factor to how well students comprehend a passage about statistics and self-assess that comprehension. Since her perspective on epistemology has multiple axes, she chose to focus on one for the purposes of depth. Mathematics was the chosen subject because it requires students to build on prerequisite concepts, and a belief in simple knowledge may have profound effects on students.

The students were to read one of two passages. Both were called "Understanding Average Scores and How These Scores Vary," and both discussed measures of central tendency but differed in secondary topic (either skewed distributions or measures of dispersion). Students were given one of two sets of instructions. The first asked them to determine if their passage is clearly written and appropriate for college freshmen. The second asked them to read the passage and teach the information to another student. This second instruction was fake, but designed to get them to take the reading seriously. All students judged their own confidence in understanding the reading on a one to four scale and completed a short survey about study strategies. Schommer's major finding was that beliefs corresponding to the "simple knowledge" factor correlated with poor comprehension and overconfidence in the reading task. A regression analysis showed that the correlation between simple knowledge and comprehension on the reading task persisted even when students' self-reported study strategies were controlled for: she found both a direct effect of simple knowledge on comprehension and two mediated effects, with simple knowledge affecting study strategies and study strategies affecting comprehension. Unlike previous studies, this was an attempt at empirically connecting epistemological views with achievement in learning. Contrast this with Perry, who connected epistemology with approaches to learning. The next major section in this chapter will discuss the ontological implications of the kind of factor analysis Schommer did and how one might challenge it.

The approach of Hammer and Elby – a different ontology

A researcher's thoughts concerning what an epistemology actually *is* will affect how she collects and interprets epistemological data; theoretical perspective, even if implicit, guides empirical practice. The purpose of this section is to discuss the ontologies implicit in the education research literature from the previous section.

By “ontologies,” I mean the *types of cognitive structures* present in the head, so assumptions about that is what colors a researcher’s methods. Ontologies in the previous literature are compared in order to preface a discussion of the explicit and tacit assumptions made by researchers using different research methods. Once this is done, I will connect these ontologies to similar constructs in the physics epistemological research literature.

Perry developed nine epistemological positions within three large categories. Although Belenky et al. called their positions “ways of knowing,” those were also essentially categories. King & Kitchener divided subjects into prereflective, quasireflective, and reflective groups. Baxter Magolda used the term “ways of knowing” as well. These researchers all took statements from their subjects and placed them into the categories used by their models. Perry and Belenky especially note that changes between large categories (for example, between dualism and multiplicity in Perry or between subjective and procedural knowledge in Belenky) involved large transformations in the student. There is no room for these models for scores being flexible across contexts. In King & Kitchener, there was some room for context since each of their ill-structured problems could be rated separately, but the global context across different subjects remained the same (all were participating in interviews discussing the same set of problems). The main way a student is identified in one of these four models is according to a score indicating which position he or she is in. The positions are somewhat Piagetian in philosophy; they correspond to cognitive structures that exist in the head and are moved through in a more or less linear progression.

Schommer's work does not have similar categories. Her criticism of the four models mentioned in the last paragraph is that they only give one epistemological axis along which a student may progress. She developed five axes and then found through factor analysis that four types of question subcategories somewhat resembling her five original axes (recall that she performed analysis only on prearranged subcategories and not all her individual questions) loaded together. These factors are equated with categories of epistemological belief, and then students are judged as sophisticated or unsophisticated based on their place on these axes. The fact that she was willing to consider more than one axis of development separates her work from the previous four models, yet there is a similarity in that all the research discussed to this point places students into categories according to beliefs the students hold in their heads.

What is the *ontology*, then, of these categories? Following Hammer & Elby (2002), I will use the term *unitary structure* as a way of describing what they are. Unitary structures are typically considered robust things that students either have in their heads or do not. This is the reason that contextual variance is not as well-explained as it is in alternatives that will be discussed later. Nuanced internal structure is not studied in belief-like ontologies, so there no analytical tools available that explain why students would display seemingly contradictory beliefs in different contexts.

Unitary structures have appeared in physics conceptual literature as well. In earlier stages of physics education research (such as Strike & Posner, 1982, McCloskey, 1983, and Clement, 1983), the focus was on student *misconceptions*, or (less controversially) *difficulties*. In those works, many students were said to hold a non-Newtonian belief that a steady force is required to maintain motion at a constant velocity. This "misconception" is said to be a strongly held and robust cognitive structure that must be overcome or eliminated for students to understand physics as an expert would, and it appears within the student's cognition completely as a discrete unit or not at all. Another well-known "misconception" example comes from Sadler, et al. (1989), where recent college graduates indicated that winter is cold because the Earth is farthest from the Sun at that time. A misconceptions perspective would say that the statement "Winter is cold because the Earth is farther" is evidence of a robust misconception that must be overcome for expertise to be achieved.

DiSessa's work (1993) developed the idea that knowledge contributing to our intuitive senses of mechanism might not exist in right or wrong structures called "conceptions" and "misconceptions." Rather, it may be made up of bits at a smaller grain size, which he calls *phenomenological primitives* (or p-prims). They are activated differently in different contexts, and are neither correct nor incorrect *per se* in absence of context. Examples such as those illustrated in Hammer (1996) can help illustrate how a p-prim perspective would look at the misconceptions in the previous paragraph. The p-prim called *maintaining agency* corresponds to a student's idea that a force is needed to maintain constant motion. In this case, the "agency" is the force, and the motion is the thing being maintained. Although in the context of Newtonian physics, this application of a *maintaining agency* idea is incorrect, there are other examples where correct ideas can come from it, for example, the fact that a source of energy is required to maintain the light in a light bulb. The college graduates who appeared confused about the seasons may have been applying a p-prim called *closer means stronger*. Again, while application of this small grain of knowledge leads to a wrong answer in the Earth context, it does a good job of explaining how one can warm himself near a fire. When asked "if it's winter in the Northern Hemisphere, what's going on in the Southern Hemisphere?" the students quickly realized that the use of that p-prim was inappropriate for the question given. A more generic term used to describe stable units of reasoning whose productivity depends on their activation in context is *resources* (Hammer 2000).

Epistemology can be treated the same way, and applying diSessa's resource ideas to epistemology allows for a challenge to unitary epistemological structures. Hammer & Elby (2002) performed this very treatment. They claim that "unitarity" is an inadequate "default presumption" in the epistemological literature. A parallel they draw to unitary theories of understanding physics compares the idea of *misconceptions* to the corresponding idea of *misbeliefs* in the epistemological domain. Just like "motion requires force" would be a unitary "misconception" a student either possesses or does not, a belief that "scientific knowledge is certain" could be considered a "misbelief" that a student possesses as a complete and incorrect unit. Although Hammer & Elby cite results (Hammer 1994, for example) that show students may have consistent epistemological beliefs within the context of a physics course, there is no reason to believe that consistency within a single context implies a unitary ontology for epistemology. To them (and me), even physics classroom contexts can vary and change to foster or inhibit certain epistemological modes.

What specific alternative, then, do Hammer and Elby offer? Instead of saying that students have rigid epistemological beliefs that are right or wrong; productive or unproductive; they might say that instead students possess a number of epistemological resources that can be activated within different contexts in locally coherent ways (Hammer et al 2005). An epistemological resource, as they describe it, should be recognizable as common sense and may be reasonably attributed to children (much like p-prims). In their model, Hammer and Elby suggest four categories of epistemological resources: resources for understanding the nature and source of knowledge, resources for understanding epistemological activities, resources for understanding epistemological forms, and resources for understanding epistemological stances.

Very young children utter things that indicate how they see knowledge. Hammer and Elby make up contexts for their examples of each of the four types of epistemological resources. I will illustrate some of their examples regarding the nature and source of knowledge. *Knowledge as propagated stuff* can be seen in use when a child is asked "How do you know we're having soup for dinner?" and responds "Because Mommy told me." In that context, the child sees the information as propagated from his mother to him. *Knowledge as free creation* is a way children understand what happens when they use imagination to make up ideas, stories, and games. For this resource, think of times when they say "I made it up!" Although we know that no creation truly comes from nothing, *knowledge as free creation* explains a resource children use to explain what is going on to them. Children also, in other contexts, might see *knowledge as fabricated stuff*. Hammer and Elby's example of this is if you ask a young elementary school student "How do you know that three times five is fifteen?" he may answer "I added 5 + 5 + 5." If the child answered "the teacher told me" or "I made it up," one could say he was using one of the other epistemological resources in this mathematical context.

Children also understand epistemological activities like finding something out, making sure of something, or applying information they know. In the language of epistemological resources, Hammer and Elby call these *accumulation*, *checking*, and *application* respectively (collectively, they are called "resources for understanding epistemological activities"). Note that this is not an exhaustive list of all resources pertaining to understanding epistemological activities; Hammer and Elby are simply listing some of the more plausible or prevalent resources. *Accumulation* reflects children's understanding that one can "get" a piece of information much like one can "get" a toy. *Checking* is also something children understand because, as Hammer and Elby put it, they have experience making mistakes and realize that "making sure" is an epistemologically productive thing to do. In cases where the child (or student) understands that the knowledge has been acquired and checked, he or she will know that there are times for it to be applied, e. g., when a rule is to be followed or telling someone else some information.

Hammer and Elby's next group of epistemological resources are termed "epistemological forms." These act as frameworks that previously defined forms act within. For example, a child needs to possess an understanding of the form *stories* before using *free creation* and *fabrication* in the context of creating a story. Other epistemological forms include *songs*, *lists*, and *rules*.

Hammer and Elby's final group of epistemological resources concerns *understanding* epistemological stances, that is, not undertaking these stances themselves but possessing the necessary cognitive machinery to engage in these epistemological activities. What these resources entail follow easily from their names. *Belief*, *disbelief*, and *doubting* are all stances one can take toward a piece of information. Aside from belief or disbelief, Hammer and Elby also identify *understanding*, *puzzlement*, and *acceptance* as resources students activate when deciding if an idea or piece of information makes sense.

Unlike previously discussed unitary views of epistemology, Hammer and Elby's epistemological resources are not organized in a hierarchy of sophistication. In strictly unitary frameworks, researchers consider development a linear motion through stages organized hierarchically. Since epistemological resources are not arranged that way, development has to happen a different way. In the resources perspective, epistemological development happens as students become more sophisticated in activating resources in appropriate contexts.

A lack of a resource hierarchy and the premise that resources are activated differently in different contexts does not imply that student epistemologies are completely fragmented. Both Hammer et al. (2005) and Lising & Elby (2005) found that consistencies can appear in epistemologies that seem belief-like. What causes this belief-like appearance, they say, is an *epistemological framing* where various resources act in a locally coherent way, resulting in stability. Redish (2004) came up with the term "epistemological frame" to connect with previous framing studies such as Tannen (1993). Framing occurs when someone uses their expectations of a situation to shape what he or she does. In Hammer's example, a student called "Louis" viewed his physics class as requiring memorization because he felt he needed the same attitude in chemistry class. In resource terms, he was activating resources such as *accumulation* (since facts, to him, were something to be acquired) and *knowledge as propagated stuff*. The physics class, then, provided a similar context, and Louis reacted by using a similar framing.

Expectations and epistemology are frequently intertwined in this way. For Louis, he was not able to change his approach to the class until his epistemological frame was adjusted. His instructor (Hammer) asked him to "try to explain it to a ten-year-old" when studying, and that jarred Louis into thinking about conceptual ideas and simpler explanations of those ideas. Of course, a simple suggestion will not always succeed in reframing physics learning for a student, but Louis's case is compelling; he was able to articulate specific examples for how the reframing helped him. It is possible to then say that after the reframing, he was not activating his epistemological resources in the same locally coherent (within the classroom context) manner.

The work by Hammer et al, (2005) and the paper by Louca, et al. (2004) describe a more fragmented view in detail, as does the chapter by Bell & Linn (2001), though Bell & Linn's view fits with the fragmented view more because of the context-dependent way their epistemological constructs are activated, not any emphasis on the constructs' ontological status. Bell & Linn note that students explain scientific phenomena differently depending on what sort of question is being asked; if they are questioned about something they learned in science class, they typically discuss those facts in terms of experiments explicitly done in the classroom context. They do not go further and make ontological hypotheses about why student behavior is context dependent in this way.

Work presented in this dissertation will avoid assuming a unitary ontological perspective. For example, I will allow for interpretations of interview data that treat epistemological utterances as indicative of resources being activated in context. In other surveys, I decide philosophically not to factor analyze data because historically, the resulting factors are interpreted as corresponding to robust, context-independent cognitive structures. I do not want to make this assumption.

Other epistemological research in physics

All the methodologies used in this thesis probe students' epistemologies and their relation to students' learning of physics. I will be comparing and contrasting the methods in terms of effort required, usefulness and richness of data, and the underlying ontological assumptions each method's theoretical framework makes. Despite the common thread, each forthcoming dissertation chapter either challenges or places itself within a different methodological ethos. Before discussing my specific chapters, though, I will first look at other important efforts to study epistemology in physics students.

Surveys

The forthcoming chapter explains my effort to modify the Maryland Physics Expectations (MPEX) survey (Redish, et al 1998). The expectations mentioned in that survey's title include, for example, (1) what students expect their physics class to entail, (2) what they expect to be required for success in the class, and (3) what they feel the point of various class activities are. Epistemology shapes expectations, however, so though the MPEX is labeled a survey about expectations, it is also inherently epistemological. To summarize for this literature review, the MPEX is a 34-item Likert-scale survey that "probes student attitudes, beliefs, and assumptions about physics." It is an outgrowth of Saul's thesis work (1998) on the "hidden curriculum," that is, those expectation-related learning goals instructors have that are neither listed in the course syllabus nor the textbook. The 34 items are divided into six clusters, of which the first three are the most central to previous work I will review later in this chapter (Hammer 1994): *coherence* (Do students see topics in physics as being coherent or separate?), *concepts* (Do students see physics as rooted in concepts or equations?), *independence* (Do students believe physics knowledge must come from authority?), *math link* (What is the role of math in physics?), *reality link* (Is physics connected with real life?), *and effort* (What effort is needed to succeed in physics?). The first three clusters correspond to those studied by Hammer (1994), which will be discussed in detail later in this review. I go into great detail in Chapter 3 about the problems with the survey and how my research group attempted to modify the MPEX to be valid for a new population and to probe epistemological issues more effectively. Redish, Saul, & Steinberg used experts to calibrate and confirm which responses would be considered favorable.

Their main application (as was the main application of the MPEX2) was to test groups of students before and after a semester of instruction to see how their expectations changed. The main results were that (1) the initial state of students differed significantly from the experts, (2) the initial state was consistently similar at large state institutions, a little more favorable at a selective liberal arts college, and a little less favorable at a two-year college, and (3) at every school studied, the overall results deteriorated, that is, students on average changed to less favorable expectations. This last result is mitigated by the fact that on the *coherence*, *concepts*, and *independence* clusters, the liberal arts college did show slight improvements.

Many researchers discussed in previous sections also wrote epistemological surveys. Perry's work (1970) featured the Checklist of Educational Values (CLEV) survey. Agree/disagree items there (such as "the best thing about science courses is that most problems have only one right answer") appear in work by Schommer (1990) and are also very similar to items on the VASS (Halloun 1997) and the MPEX (Redish, et al. 1998). Baxter Magolda (1985 with Porterfield and 1987) created the written Measure of Epistemological Reflection to devise her model. It was modified in later papers (Baxter Magolda 2001 and 2004).

The VASS (Views About Sciences Survey) is the item on the previous list I have not previously touched on. In both Halloun's original VASS paper and his interpretation of the VASS (Halloun & Hestenes 1998), he describes the six dimensions and four "profiles" within each dimension used to describe student views about physics. His system is similar to Schommer's; the six dimensions are separate axes along which students may progress. There are three scientific dimensions (concerning *structure*, *methodology*, and *validity* of science) and three cognitive dimensions (*learnability*, *reflective thinking*, and *personal relevance*). Many of these match up with MPEX clusters, for example, the *structure* dimension contains elements of *coherence* and the *learnability* cluster speaks to issues of *independence* and *effort*. VASS items ask students to analyze two responses to a prompt – note that it is not strictly an agree/disagree survey – and place themselves on a seven point Likert scale. For example one item asks, "The first thing I do when solving a physics problem is: (a) represent the situation with sketches and drawings and (b) search for formulas that relate givens to unknowns." They are also given the option of choosing "neither." Student responses were judged as *expert* if they fell within the common range of responses the calibrating teachers gave, *folk* if they chose the polar opposite to the expert response, and *mixed* if they choose a middle ground some of the teachers chose. Halloun and colleagues used the *expert* and *folk* classifications as general profile descriptors for the entire survey as well. They used the terms "high transitional" and "low transitional" to represent moderately high or moderately low agreement with expert views.

What, then, did they do with this information? Some of their 1998 paper discussed how VASS profiles are linked to achievement in physics as measured by the Force Concept Inventory. Their major finding was that the VASS pretest profile is a strong predictor of conceptual gains on the FCI. Among the students who start with an expert profile, 65% of them achieve fractional gains (that is, the fraction of the possible gain they achieve from pre to post-test) greater than 0.52. Among the students who start with a folk profile, 45% of them get gains of 0.23 or lower, and the fraction getting the high (greater than 0.52) gains is much lower than the students with expert profiles. Gains for the middle profiles fall in their proper places between folk and expert profiles. In summary, then, Halloun et al. note that epistemology about physics and achievement in physics class are strongly correlated.

A newer epistemological instrument by Adams, et al. (2006) was inspired by older instruments like the MPEX. The Colorado Learning Attitudes about Science Survey (CLASS or C-LASS) paper admits that although not all student attitudes about science are globally coherent, factor analysis (similar to that used in Schommer (1990)) can be used to determine quantitatively how coherent the attitudes are. To devise an initial clustering, Adams and colleagues used a combination of pure statistical methods (factor analysis) and *predeterminism*, which is deciding in advance which questions fit with which cluster - basically, what I did with MPEX2. Then, they removed and added statements as appropriate to produce groupings that factored better statistically.

I argue that a given survey serves as one context and even factor-analyzed information from a survey cannot be used to infer coherence more global than that created by the survey (though it can genuinely be linked to conceptual gains). My own work with surveys does not attempt this, rather, it uses surveys crudely to monitor a class's epistemological progress and compare the effect of different instructional methods to the progress of different groups.

Case studies and other mixed epistemological study methods

In going beyond multiple choice or Likert-style surveys, one sees that many studies in the literature focus on case studies, written responses, or a combination of different methods. A number of these are entirely within the realm of physics, but here I will include one perspective outside physics because it closely mirrors the mission of Chapter 5.

Ryder and Leach (1999) performed a study where eleven university science students in the United Kingdom did investigative projects in their final year of schooling. Their goal was to see how student views about the "purpose of science, the nature of scientific knowledge and the role of social processes in scientific activity" affect their project work. In the study, each student worked on an original investigation with a faculty supervisor. Six of the eleven were doing lab work, and others did a mix of modeling, database analyses, and field work. They were given general epistemological questions as part of an interview before and after the project. Some of the questions include: How do scientists decide which questions to investigate? Why do scientists do experiments? How are conflicts of ideas resolved in the scientific community?

Ryder and Leach relied on student interviews and not a video-based ethnographic approach. Their goal was not to find what influenced specific behaviors, but rather how their epistemological views shaped their activities in general. Much as my student "Patty" in chapter 5, they found one case where a students' naïve epistemological views constrained her experimental work. The student, "Susan," was to investigate the combustion of gaseous mixtures. With the data, she was supposed to distinguish between competing models of combustion. Her interviews indicated that she felt the main goal of the enterprise was to take as much data as possible and describe what the charts showed. This data-centered view, however, missed the main point; she was unable to discuss the results in terms of how they related to the theoretical models. Although Ryder and Leach discussed neither the emphasis on this part placed by the supervisor nor any interventions performed, they do cite Susan as their only example where this sort of conflict happened. They introduce the concept of *epistemic demand*, that is, “the demands which a project makes on a student to draw upon his/her views about the relationship between data and knowledge in order to make progress.” For students like Susan, “naïve” views coupled with a high epistemic demand led to trouble.

As stated earlier, many examples of epistemology and learning connection studies exist in physics. One such study documented the epistemological views of 42 male high school physics students in Canada using written essays, short-answer surveys, and interviews (Roth & Roychoudhury 1994). They were given five agree/disagree questions that did not discuss physics explicitly, and were asked to elaborate with a few sentences. The student responses were coded as relativist (which they also call “constructivist” as knowledge can be relative to human constructions), objectivist or intermediate. The first such item, for example, is “scientific knowledge is artificial and does not show nature as it really is.” A student answering “science is not artificial but based on facts” would be coded objectivist and one answering “there are multiple worldviews and science is just one of them, not more and not less correct” is coded relativist. Here, *relativist* looks more like Perry’s *multiplicity* than anything else. The student essays were to be four to seven pages and discuss “how we know and how we learn with a particular application to our subject, physics.” They were also given the Constructivist Learning Environment Scale (Taylor & Fraser 1991), a multiple choice instrument designed to further place them on the relativist-objectivist scale. Finally, eleven of the students were interviewed based largely on the questionnaires they were given earlier.

With this data in hand, Roth and Roychoudhury make a series of assertions. First, they note that most (over 75%) of students are objectivist (Perry might call this absolutist) when asked about scientific knowledge directly. When presuppositions of science and the social influence on science are mentioned, students gravitate to more relativist viewpoints. However, when talking about learning science, the students used what Roth calls “metaphors with an implicit objectivist epistemology.” These are similar to Hammer & Elby’s (2002) epistemological resources; some are listed as “knowledge as material that can be transferred” and “the mind as a container of knowledge.” When discussing physics explicitly, Roth and Roychoudhury’s subjects tended to see physics as consisting of separate mathematical and conceptual aspects (both of which are communicated by textbooks) with a separate “everyday” dimension that lab exercises touch on. Finally, Roth and Roychoudhury document that students see real value in hands-on laboratory activities and group work in both laboratory and other contexts. Though they admit their sample is limited and gender-specific, they make the point I agree with that in the classroom, epistemology must be made an explicit part of the curriculum to effect change.

One issue in play with any attempt to study epistemology is that epistemology is frequently intertwined with other aspects of learning such as incoming student expectations. Elby (1999) teased these apart explicitly in a survey where he asked physics students (mostly from community colleges near San Francisco) to take a survey after their midterm exam where they indicate how they allocate study time between "concepts, formulas, practice problems, and real-life examples." For each category of work (the examples here discuss formulas), the student can choose one of six choices ranging from "since they're not really what's tested, they're not very important, worth under 5% of my study time" on one end to "being familiar with the formulas is essential, worth over 40% of my study time" on the other. Then the students are asked to imagine a fictional student named "Diana" who is taking the class pass-fail and does not suffer from the same grade pressure. Elby's results show that students study differently themselves than they would suggest Diana study. There was no correlation found between course grade and the discrepancy between a student's study recommendations, and many students felt their ideas for Diana were appropriate for themselves. He did find that among the students who distorted their study habits the most (compared to what they would tell Diana to do), over 60% of them said Diana would get a lower grade. These students are the best examples of learners who feel doing well in the class is different than trying to achieve understanding. As Elby puts it, "failure to take this distinction into account could lead to overly simplistic interpretations of MPEX results," and this warning should apply for other epistemological surveys.

Other studies have attempted to correlate how a student's conceptual learning in physics is connected to how well he or she articulates sophisticated epistemological beliefs (May & Etkina 2002). In a physics course for honors engineering students at The Ohio State University using several PER-influenced techniques, May and Etkina had the students write Weekly Reports where they answered four open-ended questions: (1) What did you learn in lab this week? How did you learn it? (2) What did you learn in lecture and recitation this week? How did you learn it? (3) What questions remained unclear? (4) If you were the professor, what questions would you ask to determine if your students understood the material? Students answered these questions via online submission. Depending on which semester the student was in, an instrument like the Force Concept Inventory (Hestenes, et al. 1992, Halloun, et al. 1995) or similar was used to measure their conceptual gains.

May and Etkina came up with a coding scheme for each type of response and then coded each as epistemologically favorable or unfavorable. For example, they gave favorable ratings to statements where a student said he reasoned something out for himself or showed some awareness for how concepts fit together. Unfavorable codings were used, for example, in cases where the student said that information came directly from the professor. The researchers counted total "codings" for each student and then counted favorable and unfavorable scores. For the most part, the high conceptual gainers had more reflective things to say. The lone verbose student in the low achiever group was extremely authority-driven. Also, the students who did better on the conceptual instrument had more favorable codings. The statistically significant ($p < 0.05$) link, then, is that sophisticated epistemology correlates with conceptual understanding in an introductory physics class.

Chapter 5 involves case-study interviews of two students and analysis of one of them. The study involved both watching video of the students working on interactive tutorials in their discussion sections AND doing frequent, in-depth interviews featuring questions based on video-stimulated recall. Many case study projects in the literature either focus on videotaped classroom behavior or interviews, not a triangulation of both. For example, Hammer's thesis work (1994) used interviews that were similar to mine in that they were in depth and spread over multiple weeks. In my interviews, the video analysis informed question generation in the interviews.

Hammer's interview study

Hammer's 1994 paper informed both Redish and Saul's work on the MPEX and several of my future chapters. In his study, he interviewed six students several times over the course of a semester of introductory physics. After getting volunteers (and soliciting interviews from a few high-scoring students), he engaged his subjects in conversations tied directly to their course and counted on them to reveal their epistemological beliefs either implicitly or explicitly. The interviews included open questions like "How's the course going?" and "How do you like the lectures?" and more directed work such as going over graded exams. He also discussed specific content from both the chapters and current assignments with the students.

The interview data were analyzed in terms of a basic theoretical framework which went through a few iterations. Hammer's goal was to analyze student data and characterize the students as having epistemological beliefs expressible in the language of his framework and to "identify beliefs important to such characterizations." From one vague dimension concerning the importance students assign to their personal intuitions, Hammer refined the framework to one with three categories: *beliefs about structure*, *beliefs about content,* and *beliefs about learning*. Hammer originally associated each category with two extremes. Within *beliefs about structure*, he characterized student responses as being consistent with *pieces* (where they believe physics topics are separate) and *coherence* (where a student believes different physics concepts fit together in a coherent way). Within *beliefs about content*, the student extremes were *formulas* and *concepts*, with each category representing what a student may think physics knowledge consists of primarily. Within *beliefs about learning*, the extremes are *by authority* and *independent*. Here, the beliefs are about where the knowledge and/or learning come from; do students see physics as something that has to be transmitted by an authority or not? These three dimensions inspired the *concepts*, *coherence*, and *independence* clusters of items on both the MPEX and MPEX2. Both Hammer and the two later surveys say that the dimensions are not meant to be independent.

There were three criteria Hammer used to evaluate the framework. The first was recognizability, that is, others should be able to recognize the categories when they see them in the data. The next was evident involvement, or influence the categorized beliefs have on student work. Finally, he looked for consistency in order to "support the claim that students could be described as having beliefs about physics knowledge and learning." Although Hammer would later adopt a resources model that does not always allow for consistency in epistemological belief, here he sought to carefully look at any indication that was discrepant with the main characterization for each student.

Each category in Hammer's theoretical framework was illustrated by examples in the paper. An example from the *beliefs about structure* dimension is when one of his students (pseudonym Evan) said, "There's just formulas in the book that are different from what I used… I had to have that formula or I couldn't have done this problem." The quote centers on formulas, but it is coded as evidence of a *pieces* belief because Evan is indicating here that one either knows a certain piece or does not, and solving the problem depends on knowing the piece. In contrast, Hammer's student "Ken" had a *coherence* belief; when discussing the calculation of rotational kinetic energy of a wheel in ways other than the $\frac{1}{2} I \omega^2$ formula, said, "all rotation is just… at any time, it's just a bunch of particles with velocities going off tangentially." This ties a physics book's rotation unit with earlier and simpler discussions of kinetic energy. Ken was aware "of the underlying relation between the two solutions that accounted for why both were valid."

In the *beliefs about content* dimension, students are distinguished according to whether they believe physics knowledge consists of formulas alone or concepts that can be represented by formulas. Evan's "formulas" stance is shown as he gives a correct answer for the angular velocity of a plane flying in a straight line: "Looking through the chapter it was the like the only formula that would work." This view led to him having trouble seeing how an object traveling in a straight line can have angular velocity with respect to an origin not on the line. Ken, on the other hand, showed a "concepts" stance when discussing the formula $v = v_0 + at$. When asked if he accepted the formula because it was in the book or because it was intuitive, Ken indicated it was a combination of both but, "If it's just a bunch of… letters… it's not going to make that much sense to you, but if you really sit down and look at what it's saying, then it starts to make sense."

Another student, Daniel, typified the "by authority" stance in the dimension *beliefs about learning physics*. Explicitly mentioning his view about the role of a professor, he showed his belief as being "By Authority" by saying, "It doesn't matter if I can prove it or not, as long as I know that someone has proven it before . . . here I am paying 15,000 dollars a year . . . I'm not going to derive this thing for them; they're going to derive it for me and explain to me how it works." Again, Ken served as the opposing view: "So, the common sense is modified, and I mean, it's not something that you just accept… you have to sit down and think about it."

Hammer later modified his framework to allow for other possibilities. The idea of *Weak Coherence* or *Weak Concepts* was introduced when students admitted "there is a coherent/conceptual content to physics, but it is the responsibility of experts." For example, one student ("Jill") "complained that the book spent too much time 'talking about the formulas and why they work this way, and… how scientists found out… but that part… we cannot really see it ourselves." These positions were placed in the middle of the coherence and concepts dimensions. Another position, called *Apparent Concepts,* is used when a student sees physics as symbols loosely associated with conceptual content. Associations between the concepts and formulas are made "when they are apparent." According to Hammer here, a student could exhibit both weak and apparent concepts simultaneously (the two codings are lumped together for this reason).

A key link between Hammer's work here and mine in the Chapter 5 interviews is that I seek to see how student epistemological outlooks affect their learning and problem solving. Hammer noticed a difference, for example, between how "Roger" (associated with Formulas or Apparent Concepts, Weak Coherence, and By Authority) and "Tony" (of the Concepts position) discussed the straight line motion angular velocity problem mentioned above. Roger “had trouble with that” and wondered “what else can I do?” besides going for a formula. Tony describes the angular velocity conceptually in terms of watching the motion from the ground: “The faster you turn your head, that’s what the angular velocity is.” Tony’s thinking is explainable to a novice outside the course, and he had no trouble articulating it. His dedication to concepts and coherence helped in another problem where he found two connected blocks had different accelerations. He knew this had to be wrong, and was able to adjust his work to account for what he knew to be correct. Roger was unable to do this when he ran into the same problem. Similar differences appeared between the different types of students when they discussed text passages and specific formulas. Overall, his framework was consistent, though a small fraction of the time, students occasionally did behave contrary to their characterization in certain contexts. Given Hammer’s later work on the resources perspective, this is no surprise.

A major summary point Hammer gave was that students characterized by *concepts* were more “careful about building and modifying their conceptual understanding” while those who were not were more “casual.” The snippets above show the implications of these attitudes. Hammer concluded by noting that epistemological analyses can provide alternative diagnoses of student difficulties and teachers might choose to make epistemological beliefs into instructional objectives. This last view is consistent with that taken by Redish and Saul (1996) in their work on the hidden curriculum.

Work by Hogan and Lising & Elby

Elsewhere in physics, Lising and Elby (2005) showed that rich epistemological insight could be gained from their subject “Jan” when group video and interviews were analyzed together. Their interviews did not link observations and the interview questions as consistently or directly as I did, but they did argue that insights from the mixed method could not have been achieved via one of the methods alone. Hogan (1999) also did semi-structured interviews based on video, and my work builds on that in both providing more specific physics course contexts and a focus on personal (Hogan calls it *proximal*) epistemology, that is, relating directly to the student’s personal experience in the class and not the more “distant” (to the student) work of professional scientists.

Part of my goal with the epistemological interviews I perform in Chapter 5 is to show that a mixed method with interview questions based on video provides better questions and richer data than either the video or interviews would provide alone. This builds on Hogan because it focuses on “proximal” epistemologies, Hammer since the interview context is well-intertwined with the class, and Lising and Elby because video and interviews are triangulated. Unlike Lising and Elby, the video I take stimulates questions referring to the students’ in-class actions, which allows for finer-grained exploration of the students’ epistemological views. The next section will further situate this approach.

<u>The current epistemological research challenge</u>

What is a practical epistemology?

William Sandoval recently wrote a paper that is a combination of a literature review and suggestion for an epistemological research program (Sandoval 2005). In it, he champions genuine inquiry for science instruction because that is the best way to foster sophisticated and productive *practical epistemologies* toward science. He defines a practical epistemology as "a set of ideas that students have about their own knowledge production in school science." This definition is close to what I used to describe epistemology in general at the beginning of this chapter. The word "practical" is used to distinguish this type of epistemology from a *formal epistemology*, which is a set of ideas a student has about professional (or formal) science. I believe, as others do (including Sandoval and Hogan (2000)), that a student's practical epistemology is central in their formation of learning practices. Therefore, this type of epistemology merits special attention. Sandoval notes that amongst some recent literature (Bell & Linn, 2000; Sandoval & Millwood, 2005) the real reasoning behind students' written forms of argumentation is often unknown; for example, how do students decide whether or not to offer a justification step at a certain stage?

Sandoval (2005), after summarizing some recent work on practical epistemologies, cites work (such as Lederman, et al., 1998) calling for links between inquiry research and formal epistemologies. He then came up with some criteria for a research program linking practical and formal epistemologies. Even though the main point of this dissertation's case studies is not to link the practical and the formal but to connect epistemologies and learning practices, Sandoval's methodological suggestions get at the kind of fine-grained detail necessary to achieve the goals I have set out.

Sandoval's proposed research

First, Sandoval recommends authentic scientific methods in instruction. Our research group's course for the present study was too lecture-centered for us to be able to say it strictly used scientific inquiry. However, the tutorials we employed at Maryland *do* involve guided and interactive engagement and we changed the focus of the lab away from simply verifying the rules discussed in lecture (Redish & Hammer 2009). The course is therefore closer to scientifically authentic than a "traditional" physics course; however, an extension of this work into our university's inquiry course for pre-service teachers may prove insightful.

He goes on to recommend examining practical epistemological ideas. This would seem obvious if one's research program aims to connect practical and formal epistemology, but much of the nature of science literature (for example, Khishfe & Abd-El-Khalick, 2002) focuses only on formal epistemologies. Sandoval goes on to note that classroom discourse is one of the best places to study individual epistemologies. I could not agree more with this, and it is a central aspect of our group's case studies. Because I watched my two subjects in tutorial every week and devising questions based on their interactions with the tutorial material and groupmates, I can say that classroom discourse forms the heart of my analysis of these students and their (largely practical!) epistemologies.

Another of Sandoval's interests is comparing practical and formal epistemologies, that is, how a student views her own learning needs differently than the needs she perceives as necessary for professional scientists. While this seems an interesting goal because learners can encounter difficulties when formal and practical epistemologies can be disconnected in one classroom context, the goal assumes a unitary form for these epistemologies. If one believes that epistemological "beliefs" manifest as a local coherence activated in a certain context, there is no way for there to be one single practical or formal epistemology within a person. One can call classroom-activated coherences the practical epistemologies, but all that can be learned about is a specific context. Certainly, the MPEX2 can be used or modified to explore formal epistemologies, but philosophically, my research's central focus has been the practical, as classroom-centered epistemologies are most relevant for students of introductory physics who might not take much more physics in college (Hogan 1999). It may yet be interesting, though, to determine if there is any framing that students can do in both classroom and formal contexts. This framing could bridge college and more professional science work for students.

Sandoval also calls for an examination of epistemologies across disciplines. I agree that this is a worthwhile pursuit, although this dissertation does not leave the domain of physics. Finally, Sandoval is interested in a developmental study of epistemology. A longitudinal study across the age levels he suggests (a gap of ten years) is not possible here, but I followed my subjects as far as I could through one course. Sandoval thought one of my techniques is less than feasible, and I hope to challenge this assertion about using video prompts in interviews:

> "We need to understand how learners' participation in forms of discursive practice elicit and change their epistemological ideas. Making this link requires detailed observation and rich analysis of classroom interaction. For instance, using video to prompt recall of the epistemic goals being pursued during a particular class discussion. This approach seems difficult, as interaction analyses require so much time as to make it highly likely that relevant episodes would be identified only long after the end of an intervention."

My claim is that this approach is not as difficult and time consuming as stated here. In Chapter 5, I hope to give a proof-of-concept for showing how video prompts can help inquire about epistemic goals without waiting until long after instructional interventions.

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Chapter 3: A Large-N Survey: The MPEX2

A basic constructivist tenet of physics education research states that students do not enter our classes as "blank slates," that is, they come into a class with knowledge that affects the way they learn physics. Many of the early papers in PER applied this principle to conceptual knowledge. The work of Redish, Saul, and Steinberg (Redish, et al, 1998) used that idea in a different way: they were curious about the attitudes and expectations students bring into a class. The Maryland Physics Expectations Survey (MPEX) was designed to probe the effects of physics courses on their students' *cognitive expectations* about physics. Cognitive expectations consist of views about what students expect to constitute "knowledge" and "learning," both in general and in the context of their physics class. I care about an expectations survey in the context of this dissertation because expectations and epistemology are often tightly intertwined.

Redish and his coauthors noted that instructors often have expectation-related goals in their classes. We would like our students to see physics as a connected whole and as something they need not accept from "on high." However, these goals are often not expressed formally in the syllabus. Even when they are, that may be the first and last mention those goals get. Therefore, Redish et al refer to these goals as part of the "hidden curriculum." In the teaching efforts to be described in this chapter, learning goals are made more explicit and woven more tightly into the instructional materials. Based on research presented in this chapter and elsewhere, my belief now is that achieving expectational goals depends on "unhiding" that part of the curriculum.

As stated in the previous chapter, the original MPEX study, like this dissertation, draws from Hammer's thesis work (Hammer 1994). He interviewed six students in an introductory physics class, and asked extensive questions about how the course was going and gave problem solving exercises. The rich transcripts that followed provided the basis for his thesis. He identified three dimensions along which to probe student epistemologies: *coherence*, *concepts*, and *independence*. *Coherence* refers to the connection of physics concepts into a unified whole. For the purposes of a survey, a "favorable" coherence view would be that the concepts and facts in physics fit together. An opposite view would hold that each chapter or unit in a physics book is a separate piece of knowledge. The *concepts* cluster refers to the place conceptual knowledge holds in the discipline as opposed to, say, mathematics or formalism. *Independence* refers to the source of physics knowledge: is it a matter of constructing meaning, or simply of absorbing knowledge from authority?

The MPEX authors came up with questions that probed these dimensions in the context of physics class. In addition, they added three more item clusters: *math link*, *reality link*, and *effort*. The reality link cluster probes beliefs about whether or not physics is related to real life and whether it is even useful to think about that link. The math link cluster probes beliefs about the proper role of mathematics in learning physics. Effort comprises beliefs about the kind of activities and work needed to make sense of physics. All of the questions were placed on a five-point Likert scale from strongly disagree (1) to strongly agree (5).

As Saul noted in his thesis (1998), the MPEX is not a valuable instrument for looking at individual students. Rather, it's designed to monitor the change in a class over the course of a semester. In this way, it can serve as an instrument that evaluates the effectiveness of curricular modifications. In the following sections, I will describe my changes to the survey, a validation attempt, and some ways in which even this crude instrument can tell us interesting epistemological things about some of our classes.

What is wrong with the MPEX?

Redish and his colleagues presented the MPEX as a "first step" towards exploring issues relating to student attitudes and the "hidden curricula" that appear in our classes. Strictly speaking, then, there is nothing "wrong" with the MPEX. For the purposes of this dissertation, though, I will be concerned about ways to improve the MPEX's focus on epistemology, specifically, contextualized responses to situations that might come up in class.

The only cluster that I saw a large problem with was the effort cluster. Results from Saul (1998) indicate that at every school using the MPEX, there was deterioration in that cluster. Saul's original interpretation was simply that students do not put in as much effort during the course as they expect to at the outset of the course. His speculation is that a sort of "New Year's resolution" effect may be going on: the students might start out assuming they'll be willing and able to do any number of different things to succeed. Later, the course reality will set in and the students will then report what they actually did. In that way, the effort cluster reflects goals and time constraints of the students as much as their actual views about learning. Part of Saul's reproducibility study on the MPEX gave the survey at both the end of the first semester and the beginning of the second semester. The effort score for his classes (with little outside influence other than the final exam) goes up literally over New Year's Day even though it had deteriorated in the previous semester. It makes sense to me, then, to drop this cluster.

More generally, several MPEX items have weak contextualization. Imparting a specific context to a survey item allows a student to grasp the idea more concretely. It also (I hypothesize) helps the validity of individual responses. When a survey item remains abstract, a student will fill in his own context and the ultimate interpretation of the response remains ambiguous overall. One context the student may fill in for himself could even be "reflecting on my learning quickly for a physics survey." Even questions that look contextualized might be interpreted in different ways. For example, the MPEX item "only very few specially qualified people are capable of really understanding physics" would depend on what "physics" is being talked about. Physics as done in an introductory class may differ a lot from advanced physics, so the context a student fills in (professional science versus classroom physics) would make the difference as to whether this item activates formal or practical resources as Hogan (1999) might distinguish.

Another concern involves the interpretation of MPEX items as "positive" or "negative." While the calibration of the items with the expert control group will not be disputed here, the valence of some responses may be inconsistent with the students' epistemology. For example (Elby – EBAPS 2008), one MPEX item asks: "My grade in the course will be primarily determined by how familiar I am with the material. Insight or creativity will have little to do with it." A student could be epistemologically sophisticated and *understand* that physics requires insight and creativity; however, if her class focuses on memorization, she could accurately report on the state of the class and be given a negative expectation score for that item. Since a survey user cannot know in the moment whether the survey was inspiring her to use a personal context or classroom context, he cannot tell whether her personal epistemology or her sense of the course's expectations is being revealed. I stated above that my new goal for MPEX was to get more at epistemology and less at expectations, so I tried to change the survey items so there was less potential for confounding influences in the responses. In a physics class, there will always be some mix of epistemology and expectations. From a research standpoint, it is in my interest to remove the items that are more susceptible to ambiguity caused by students' context-dependent framing.

Since the MPEX is used as an evaluation of a course, and not an assessment for individual students, perhaps student "reporting" on the positive or negative epistemological aspects of a course is not a bad thing. However, since my current study cares more about the personal epistemological views students hold, I will try to focus on those views (within the context of a physics course) as much as possible. Although I do not use the new MPEX to profile individual students, I would not want the test to artificially underestimate or overestimate someone based on his (possibly correct or incorrect) stance on a specific course. I will show later that enough complications arise when students are retested on the items in interviews.

<u>Specific changes from MPEX to MPEX2</u>

Removing MPEX items

A round of changes preceded my involvement in the MPEX survey project. I will list those changes here. Later, I will discuss my validation efforts with the MPEX2, and the changes that resulted from that series of interviews. Appendix A lists all of the MPEX2 items in their most recent form.

Thirty-four items are on the MPEX survey. Eighteen of them were eliminated outright from the MPEX2. Five of these were items 3, 6, 7, 24, and 34: the effort cluster. For example, item 3 reads, “I go over my class notes carefully to prepare for tests in this course” and item 6 reads, “I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text,” and item 7 reads, “I read the text in detail and work through many of the examples given there.” The effort items all discuss specific activities students can put effort into in order to succeed. Since they are not designed to probe student epistemological stances, I eliminated them all.

Eight MPEX items were not scored along with a particular cluster, and only contributed to a student’s “overall” score (5, 9, 11, 23, 28, 30, 33, and 34). One of these, #9, was completely altered and will be discussed later. The other seven were eliminated from the survey. Three of these were eliminated for being very course-specific. Item #23 says, “The main skill I get out of this course is learning how to solve physics problems.” Item #30 says, “The main skill I get out of this course is to learn how to reason logically about the physical world.” Item #33 says, “It is possible to pass this course (get a “C” or better) without understanding physics very well. The course-centered nature of these items has a similar problem as the effort cluster mentioned earlier: while interesting for instructors, these items have the potential to be ambiguous with respect to what they are probing. A student could believe conceptual understanding is as important (or more so) than problem solving and honestly respond negatively on these questions based on an activation of her "course-reporting" context. While one might not be able to remove all connections between this survey and the students' course, I do suspect that these items as they are tell us little about students' personal epistemologies when there is a conflict between those epistemologies and their course-specific expectations. Elby's study of "Diana" shows that these conflicts are very real for a large number of students (Elby 1999).

The other non-clustered questions I removed were eliminated for similar reasons. Item #5 ("Learning physics made me change some of my ideas about how the physical world works") can have a positive or negative connotation depending on the student's initial *conceptual* knowledge of physics (maybe it did not need changing), and I would like MPEX2 items to be independent to the extent possible from a student's conceptual understanding. Similarly, the positive/negative valence of #11 ("A good understanding of physics is necessary for me to achieve my career goals. A good grade in this course is not enough.") would depend on the student's career goals. For many people in our classes, knowledge of specific physics material is not important for future success in their major or job.

Item 28 ("Spending a lot of time (half an hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.") was removed because, again, an epistemologically sophisticated student could agree with the item if real-life time and course constraints make that the pragmatic choice. Schoenfeld's result (1989) that students learn to give up on a math problem after a few minutes does not address epistemology in the way that removing this MPEX item attempts. Item #34 ("Learning physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text") has a similar issue, as a survey user would not be aware of the student's initial thinking and organization of knowledge.

Wording changes in MPEX items

Before I performed validation interviews, some of the MPEX items that "survived" to the MPEX2 were altered slightly. I changed the verb tense from present to future on MPEX posttest items 13, 25, and 29 and kept the tenses the same for all administrations of the survey. Item 13 originally read in the present tense, "My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it." Item 25 originally read, "Learning physics helps me understand situations in my everyday life." Finally, item 29 on the original was "A significant problem in this course is being able to memorize all the information I need to know." Changing these three items to future tense is consistent with the "expectational" nature of the survey, and is especially appropriate for a pretest. A student who has not taken physics, for example, would not know whether physics does help understand situations in her life, but might have an expectation as to whether it will.

MPEX item 2 was changed from "All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems" to

“The main point of seeing where a formula comes from is to learn that the formula is valid and that it is OK to use it in problems.” I changed the item from first person to third person to make it independent of whether a student learned anything from such a bit of lecture. Also, “seeing the point” of something is a key issue I care about epistemologically. Finally, the phrase “derivation or proof” became “where a formula comes from” to make the idea in the item slightly less rigid and formal and more appropriate for a less mathematically oriented class.

I heavily modified item 9. “The best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail” became “To really help us learn physics, professors in lecture should show us how to solve lots of problems, instead of spending so much time on concepts, proofs of general equations, and one or two problems.” I added a lot of detail to the activities mentioned, and the action of “problem solving” switches from the student to the instructor. This latter change focuses the item on “absorbing” information from the instructor.

Some other items changed subtly with small differences in wording. I added the clause “Although physical laws may apply to certain simple situations like we see in class and lab…” to the beginning of item 10 (originally “Physical laws have little relation to what I experience in the real world”). This clearly distinguishes class and lab from the real world, and forces students to think about that distinction. In item 18 (originally “To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed”), I changed the phrase “To understand physics” to “When learning a new physics topic” because “To understand physics” is broad and vague. Also, I changed the wording “I sometimes think about my personal experiences” to “it’s important to think about my personal experiences.” This gets around problems MPEX researchers had with the effort cluster, because the item is now independent of whether the student thought about personal experiences or not.

I made small changes for a variety of other reasons. Item 20, (“If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it”) was changed to “If I don’t remember a particular equation needed for a problem in an exam I can probably figure out an (ethical!) way to come up with it, given enough time.” I added the clause about time because I did not want students being considered unfavorable if they were not confident they could come up with an equation due to time pressure. Item 8 (“Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course”) was changed so “understanding physics” was the focus, not succeeding in the course.

One last large change exemplifies how I sought to contextualize questions. MPEX’s item 21 reads “If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable. (Assume the answer is not in the back of the book.)” The new version says “When doing practice problems for a test or working on homework, if I came up with two different approaches to a problem, and they gave different answers, I would not worry about it; after finding out the right answer, I’d just be sure to avoid the incorrect approach.” The new wording adds the context for the problems. Also, with the assumption that a right answer is discovered, the new version forces students to reflect on whether they see value in reflecting upon why a seemingly-sensible approach was incorrect. On the original version, by contrast, a student could “strongly agree” because of her epistemological view that learning doesn’t involve sorting through one’s ideas *or* because she’s imagining a context (say, a final exam) in which her primary goal is getting the right answer.

The preceding paragraphs describe the changes I initially made to some of the items. The next section describes items that were added. Finally, I describe my validation interviews, which involved talking to our algebra-based students about the survey items.

New items for the MPEX2

In addition to deleting and rewording items from the original MPEX, I added new items within the framework of the three important clusters: *coherence, concepts*, and *independence*. The new items come in three varieties: simple agree/disagree items, statements taken from the Epistemological Beliefs Assessment for Physics Science (EBAPS) (White, et al. 1999), and scenario items where students respond to two debating students. This last group of items was inspired by items on the EBAPS.

The simplest class of new items are simple agree-disagree items that look like other MPEX items. An example of one in my *concepts* cluster is “Adept use of formulas is the main thing needed to solve physics problems effectively.” A new *independence* item is “It wouldn’t matter if I didn’t get my homework returned to me as long as I knew which questions I got wrong and I had the solutions to study.” Items like these do not stray far from the spirit of the original MPEX.

Elby and others formulated the EBAPS differently from surveys like the MPEX and VASS (Halloun 1997). They cite three main ways the EBAPS is different: they use varied item types, the contextualizations are rich, and fewer of the item statements are obviously favorable or unfavorable. Given that I did not feel committed to a strict Likert survey, all three of these qualities are favorable to me. Five EBAPS items I chose to include in MPEX2 (numbers 1, 11, 13, 15, and 17 on that survey) fit within the standard MPEX Likert scheme.

Item 1 reads, “Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn’t think about her own experiences; she should just focus on what the book says.” This item was left unchanged in MPEX2. EBAPS items 11, 13, and 17 referred to both physics and chemistry teachers on the original survey; the references to chemistry were removed for the MPEX (*11*: When handing in a physics or chemistry test, you can generally have a sense of how well you did even before talking about it with other students. *13*: If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.) The MPEX2 version of EBAPS item 13 replaces the sample questions and practice problems part with “thinking outside of class” to emphasize the independence aspect (a professor can prescribe practice problems).

EBAPS item 15 reads, “When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the ‘big ideas’ might be helpful for specially-written problems, but not for most regular problems.” Item 17 originally read (before removal of the chemistry reference), “To understand chemistry and physics, the formulas (equations) are really the main thing;

the other material is mostly to help you decide which equations to use in which situations." A sixth longer item, EBAPS #24, is a "debate" item where the student reads a dialogue between two fictional students and decides her relative agreement with each person. In it, one student argues that a good science textbook should link material from different chapters together since the material is not really separate. His friend argues that each chapter is about a different topic, and these topics should remain separate.

EBAPS is domain-specific in that it covers physical science, but I wanted items for the MPEX that are physics specific. Therefore, I wrote items in the style of EBAPS, but using specific physics examples. One example reads:

> Consider the following question from a popular textbook: "A horse is urged to pull a wagon. The horse refuses to try, citing Newton's 3rd law as a defense: The pull of the horse on the wagon is equal but opposite to the pull of the wagon on the horse. 'If I can never exert a greater force on the wagon than it exerts on me, how can I ever start the wagon moving?' asks the horse. How would you reply?"
>
> When studying for a test, what best characterizes your attitude towards studying and answering questions such as this?

Then, five options are given ranging from "studying these kinds of questions isn't helpful, because they won't be on the test" to "Studying these questions is extremely helpful, worth a whole lot of my study time." The part about these kinds of questions not being on the test is expectational in nature, but the beliefs about studying that are being asked about (only one of the five choices mentions the test) are epistemological and germane to the interests of this study. Other questions in the same style deal with group work and the role of textbook equations in studying. Situational items like this address a problem with the MPEX: the MPEX measures what students think they think as opposed to what they actually think. In a survey context, one cannot completely remove this concern, but adding EBAPS-style situations are more likely to get a true sense of how a student would behave in a real situation.

It should be noted that on the original MPEX, the researchers established "face validity" by calibrating the items with a group of expert physics professors. A strong consensus (Redish, et al. 1998) established which answers were favorable or unfavorable. Since many of the MPEX2 items came from the original survey and another significant subset came from another established survey, I did not repeat the calibration step for the MPEX2. Since, as I discuss later, the MPEX2 is to be used as a course evaluation with respect to certain instructional goals, any new item responses were rated favorable or unfavorable depending on the instructional goal corresponding to the clusters in which they were placed.

Validation Interviews

Once I finished a round of modifying and adding items to the MPEX2, I interviewed students to test the construct validity of the survey. By going over the interview items with the students after they took a paper-and-pencil version, I could check for test-retest reliability and simultaneously weed out parts of items that led to ambiguities between expectations and non-course-specific epistemological views. Appendix B contains the interview transcripts using items of the original MPEX2. Appendix A contains the revised version.

I interviewed four volunteers from the second semester introductory physics class (PHYS 122), referred to here by pseudonyms Anne, Molly, Bruce, and Theo. The students had taken the paper-and-pencil survey about two weeks prior, and the final exam happened between the two testings. I was the interviewer. For each student, I read each MPEX2 item and asked for the agree/disagree response where appropriate. Also, I asked the student to elaborate on why they gave the response they did. Full transcripts of these interviews are in Appendix B.

In general, students read the questions as intended. Of course, individual differences in word interpretation (such as the meaning of “solving,” “beneficial,” “regular physics problems,” and others) happened all over the place, but most of those instances were minor. For example, my subject “Bruce” saw two different kinds of “benefit” in responding to item 23 about the advantages of having a group member who already understands the material:

> “…it was beneficial if one person knew it already, but it was also beneficial if we had that discussion… if nobody was exactly sure what was going on.”

For him, two kinds of benefit led him to a neutral response. Two of my other subjects each took one side and that shaped their responses. In fact, I want the MPEX2 to tease out cases where meanings of certain words reflect epistemological belief.

Other idiosyncrasies in students’ responses may have arisen from the course they had just taken. Students in our reformed-curriculum course picked up that there was something different about it, and they know that their course is geared toward issues the survey is probing. In addition, my interview subjects noticed similarities within clusters of questions. For example, both male subjects noticed the “reality link”-style items. Theo pointed out that in item 22, “I read it the same way, it’s just slightly worded a little bit differently, and you threw in the lab in this case, but I still think it’s the same question.”

Several responses from the interviews led me to make changes in the wording of MPEX items. Note that item numbers here are from the old version. Appendix A has the most recent numbering that accounts for new wordings and eliminated items. In item #2 (currently "All I need to do to understand most of the basic ideas in this course is just go to lecture, work most of the problems, read the text, and/or pay close attention in class), "read the text" was listed as the first item in a list, and that mattered. Theo indicated in his interview that participating closely in class and relating the material to real-life examples was very important. This is an epistemologically sophisticated stance, and it's consistent with his "disagree" response, but his main reason for disagreeing was distaste for the text. Anne didn't use the text at all, and Molly didn't mention it. I therefore changed the item to mention lecture and problems before the text.

I changed what is now item 5 to provide some context. Previously, it read "Adept use of formulas is the main thing needed to solve physics problems effectively." It now reads, "In this course, adept use of formulas is the main thing…" Note that the item has now become about expectations. Although I wanted to shift the focus to epistemology when possible, it behooves us to explicitly make a question about expectations if it is unambiguous and fits with other items in the concepts cluster. Also, I had to supply context for this question; doing that was more important than steering clear of expectation-related items. On this item, three of the subjects were neutral, because they recognized the ubiquity of formulas in some of their problems, but they realized they may not have been a *main* centerpiece. Theo pointed out an important distinction: "Not for this class. I mean, my friends in the other physics classes, that's all they know, are formulas, so I would agree with it for that, so I think that 'physics problems' is kind of more general. Physics problems in this class, no." The wording change is minor, but now it assesses student experience with formulas in the context of their own physics course.

Item 8 got a subtle wording change. In "Physics is related to the real world, but you can understand physics without thinking about that connection," I changed the word "you" to "I." I want MPEX2 to probe personal beliefs about physics knowledge, and two of my subjects (Molly and Bruce) explicitly made the distinction that they could see *some* people as being able to understand physics without connecting it to real life. Their response reflected a mix of their own experience in the course and this hypothetical set of reality-divorced physics learners. I want to remove ambiguities in interpreting student responses, so to tease apart their views on themselves versus experts, I switched the item to a first person format.

I changed two items (currently items 11 and 14 – there was a renumbering that will be explained in the next paragraph) because of language related to getting an answer or working through a solution. Item 11 read, "When doing practice problems for a test or working on homework, if I came up with two different approaches to a problem and they gave different answers, I would not worry about it; after looking up the right answer, I'd just be sure to avoid the incorrect approach." The words "looking up" were changed to "finding out" because the focus of that item is on what a student would do with a correct answer. I do not really care how the student got the correct information, I simply want to know if he or she would not reflect upon an incorrect approach upon getting the right answer. Item 14's change (previously: "If a problem on an exam does not look like one I've already done, I don't think I would have much of a chance of being able to solve it") was from the phrase "solve it" to "work it out." This came from a general concern of ours that for students, "solving it" may mean simply "getting sufficient points." The new wording contains the connotation that some substantive understanding is going on, and not just scraping for points.

Perhaps the most telling change of all involved eliminating item 3 and renumbering the rest (so, for example, items 8, 11, and 14 above were 9, 12, and 15 in the original version). The item reads "In doing a physics problem, if my calculation gives a result that differs significantly from what I expect, I'd just have to trust the calculation." In disagreeing with it, Molly noted that "There's a lot of things that go wrong in a calculation." Theo noted "I don't trust my math enough to be like that." Disagreeing with the item is the epistemologically favorable outlook. Ideally, when a student gets a result that differs from expectations, he or she should think it out and reason about what could have gone wrong. However, these students did not disagree for those sophisticated reasons. They disagreed because they do not trust their math ability. This is a perfect example of a "false positive," and I suspect it is one that would show up a lot in algebra-based course. Those students self-select into the less mathematically sophisticated course, and many of them express lack of confidence with math during tutorials and in informal interactions with TAs. Item 3 may be a good item for an engineering course survey, but I eliminated it from the MPEX2 because my population did not have that mathematical confidence and sophistication.

Test-retest reliability

It is worth checking whether the student responses in the interviews correspond with the answers they gave on the paper-and-pencil version even though one should expect mismatches given the change in survey context. A simple comparison of answers may give us an idea of how fragile a student response is. This is complicated somewhat by the fact that some time (two weeks) and a final exam occurred in between the two administrations. Student affect and self-efficacy can be affected by such a large test, and so some shift in attitudes may be expected.

Only the first 34 items in the version studied for reliability were covered in the clusters, and 33 of them were in multiple-choice format. I compared the original answers from their paper-and-pencil version to their interviews, looking only for the valence of each response (favorable, unfavorable, or neutral). Out of the 33 responses, Anne matched on 26 (79%) of them, Bruce matched on 23 (70%), Molly matched on 19 (58%), and Theo matched on 25 (76%).

Those percentages are not particularly high, and for a survey as crude as the MPEX2, I do not really know what a high test-retest correspondence would be. However, I am interested in exactly how much each student can potentially move from test to retest. If students move consistently in one direction or the other, it might indicate unreliability of the paper survey, interviews, or both. Alternatively, it might mean students are too epistemologically fragile to study reliably in this way. In the epistemological resources framework, fragility would most likely come from differences in survey context. Though the questions on the survey itself do not change, the aforementioned final exam (and final grades) may have affected the resources activated within the students during the survey. For example, a bad score on a certain concept might shift the student toward activating resources centered on understanding rather than ones that would support getting through material quickly.

To get a feel for what happened between test and retest, I gave each student a score for each question representing a "move toward favorability" in the interview. Therefore, if a student gave a neutral response on the survey for a question, and gave a favorable response in the interview, she would get a +1 for that question. If someone gave a favorable answer on the survey and gave an unfavorable response in my interview, I scored that as a -2 shift. I summed up all the item scores for my four interview subjects. Anne and Bruce scored -1 total, Molly scored 5, and Theo scored 6. That means Anne's and Bruce's motion tended to average out to nothing overall. Molly and Theo were more favorable in the interview.

I cannot infer too many hard, conclusive facts from this data. On one hand, two students barely changed at all, which indicates that individual question fluctuations wouldn't have much effect on a class as a whole. On another, two students seemed to change quite a bit. One can hypothesize some reasons why this happened. The original paper-and-pencil survey is given under more apathetic conditions toward the end of a course. It often happens near final exams when students have other worries. In an interview, there's no time pressure, the situation is more relaxed, and in my case, the exam was over and the students had a chance to be more honest and reflective. Of course, with my small sample size, I cannot eliminate the possibility that some students will go in the opposite direction. Maybe a bad exam experience can drive a student to contradict himself later in an interview.

Likewise, if a student sees an exam that rewards conceptual understanding, it might lead to a favorable shift.

In summary, the crudity of the survey and questions about reliability lead me to believe that the MPEX2 is not a particularly valuable instrument in of itself to assess how an individual student views epistemology in the context of physics class. An interview where students are free to explain, contextualize, and be specific would yield much richer and more reliable data. However, the point of coming up with a survey in the first place is so whole classes can be evaluated quickly. My validity testing has endeavored to make MPEX2 suitable for that purpose.

Using the MPEX2

Item clusters: from fundamental assumptions to MPEX2 specifics

In the research literature, surveys concerning student views on the nature of science often cluster their items using statistical factor analysis (Halloun 1997, Adams, et al. 2006). Items that "factor together" become major groupings, and items that do not fit cleanly into a factor grouping are closely scrutinized. Even if a survey is designed with clusterings in mind, those groupings are subject to factor analysis for "reliability" testing of the clusters.

Surveys employing factor analysis make tacit fundamental assumptions about the nature of students' epistemologies. For a cluster to factor properly, students on average will need to give consistently favorable or unfavorable responses within that cluster. Any discrepancy would represent an inconsistency, and these inconsistencies are blamed on the survey; the item that correlates poorly with other items in its cluster is considered "unreliable." For example, if a survey wanted to probe whether students robustly believed that knowledge is absorbed from authority versus something you can build from your own experiences, the use of factor analysis to cull "unreliable" items relies implicitly on the assumption that the student *has* either transmissionist beliefs or the opposite fairly consistently, and the role of the survey is to uncover that belief.

We know, however, that a student's epistemology can display variability across contexts. A student may indicate that a clear set of lectures is required to understand science well. In itself, this is a small transmissionist statement; it implies that learning is difficult or impossible without the help of a good lecturer. However, a student who believes this may also see transmission of knowledge as less useful in a small group environment. She might think that closer collaboration and free questioning is the best way to learn in that context. My fundamental assumption, backed by substantial evidence (as mentioned in Elby & Hammer 2001), is that students' science epistemologies are sensitive to context in just this way. Students have resources corresponding to different ways of thinking about science, and which resources get activated depends on context. Hammer and Elby's discussion of resources discusses this idea more fully (Hammer & Elby 2002). The resource concept is an outgrowth of diSessa's p-prim work (1993), in which small bits of physical intuition can, depending on context activation, result in either correct or incorrect answers. An analogy between p-prims and epistemological work would bet to say that an epistemological resource is neither favorable nor unfavorable in of itself, but leads to manifestations on surveys or in class we could judge as favorable or unfavorable.

An example from the interviews illustrates how contexts activate favorable or unfavorable responses to MPEX2 items, leading to an "inconsistency" in the student's epistemology that reflects real variability in her epistemology, not a problem with the survey items. For example, "Bruce" disagreed with the item saying that insight or creativity has little to do with success in physics (see Appendix A, item 12):

> S: Uh, disagree, because, I mean, all we do is the insight and creativity with the modeling, you know? Since we don't have… say I was familiar with the material on electricity, I understood the equations, and all that, but… [Mmm-hmm] it didn't really come full circle, it didn't reveal itself as an actual concept until we used the creativity of using the models, and being able to understand, supposedly, it flows like water, there's no definite thing you can call electricity you have to use those models, and you have to use creativity and insight to help, help the concept become fully realized.

However, when asked a more personal question about whether he could solve an unfamiliar problem (item 14), he replied:

> S: Um, I guess neutral, it depends on the case. Uh… I mean, I guess practice makes perfect, so if I haven't seen something before, then it's gonna be hard to totally go at it, but it's not to say that I wouldn't… have much of a chance of being able to solve it. I definitely think I could probably come up… bring something else to the table that I might… I wouldn't totally forget it, and skip it, and go on to the next question, you know? You definitely have to go back and try to work with it and try to reason it out, and try to figure out… "what else do I know that I can apply to this and maybe, like, find some answer."

So not only was the response different, but Bruce explicitly noted in the second answer given here that his response to this question would depend on the case.

Consequently, any factor analysis that would question or eliminate items simply because they load inconsistently with other items violates my fundamental assumptions about students' epistemological views. I not only allow but expect context-dependent inconsistencies within a cluster. Culling and revising the survey based on factor analysis would undoubtedly increase the statistical reliability of the MPEX2, but at the expense of context-rich validity.

If my MPEX2 clusters are not formal factors, then what are they? I consider them rough goals for instruction. My final MPEX2 results, after all, are meant to serve as an evaluation of how well our courses promoted favorable attitudes pertaining to coherence, concepts, and independence. I do not assume they are orthogonal or independent, but I believe that instructors can address each of these issues individually in a lesson if desired and one can assess how well a group of students has progressed along one of these dimensions individually. The best way, then, to make sure my items really evaluate students along those three axes is to validate the items one by one. That was the main goal of my interviews.

All my MPEX2 analysis is done in the three main clusters of *coherence*, *concepts*, and *independence*. However, I subdivided the coherence and independence clusters further. It may seem foolish to do that when I do not analyze the data from those clusters, but subdivisions provide potential breakdowns for further analysis within a cluster and tie the versions of MPEX together. *Coherence*, for example, is divided into *coherence math*, *coherence reality*, and *coherence other* groups. Revised items from the old MPEX *math link* cluster are in *coherence math*. I recast that as a coherence cluster because those items probe the extent to which students see math as connected to other aspects of physics. The way those two things fit together is a coherence issue. Likewise, *coherence reality* contains old *reality link* items that probe the extent to which the student sees physics as connected to everyday experience. *Coherence other* contains coherence items that do not fit into either of the previous categories.

I divide *independence* cluster into two categories: *independence personal* and *independence epistemological*. While both groups deal with epistemological issues, *independence personal* items are explicitly personal: the three items each ask students to assess their ability to solve new problems and evaluate their performance on exams. In short, those items deal with self-efficacy with respect to novel problem situations (Bandura 1994). *Independence epistemological* items are more general; they discuss the role of lectures, the text, other students, etc., in the learning process. There are currently nine of these items on the MPEX2, compared with three *independence personal* items. Further breakdown of this cluster may be helpful in the future. Appendix A lists the final question breakdown across clusters and subclusters.

<u>*Using the MPEX2 for course evaluation*</u>

MPEX2 goals and course reform

In the Fall of 2000, when the University of Maryland started using tutorials in the introductory algebra-based physics classes, my group found that using our interactive tutorials in discussion sections led to gains on instruments like the FCI and FMCE. Other groups using active learning methods often report similar gains. However, epistemological gains as measured by the MPEX were not easy to come by. The MPEX has been given to thousands of students, and this result is robust in large lecture classes, even when my PER group was in charge of the whole course. Despite the fact that a big instructional goal of the course was to improve student epistemologies as measured by the MPEX (one could say our instructors "taught to the test!"), we could not get gains on the survey.

Our hypothesis was that although we could send overt messages about the interconnectedness of physics and the importance of concepts, it is possible that covert messages or "hidden curricula" (Saul 1998) might have worked against us. The tutorials (McDermott & Shaffer 2002 – we also used prepublication sheets furnished by the Maryland research group), conceptually helpful though they were, might have been sending the wrong message to students. They were (and still are) heavily guided inquiry tasks that my group has seen unintentionally teach students that their intuition is not to be trusted. Our next round of tutorial modifications added explicit epistemological focus. Appendix E shows a sample tutorial after the change. Notice that after the change, the tutorial included questions where students had to be reflective about the learning process, for example, this item at the end of our Newton's Third Law tutorial:

> C. (Work together) We intended this tutorial as a lesson not just about Newton's third law, but also about strategies for learning physics concepts that seem to contradict common sense. What general strategies are suggested by this tutorial—strategies you might be able to use with counterintuitive concepts appearing later in the course? This is the most important question in the tutorial.

The problem with including epistemological questions in the tutorials is that students see them as "content-free." Teaching assistants are trained to explicitly draw out responses to those questions if the students don't volunteer answers.

The Maryland PER group was already using the MPEX2 to evaluate courses once these tutorial changes took effect, so I will display results from that survey to discuss the effectiveness of our curricular reforms. Following our original MPEX work, if, for example, "agree" was the favorable response, both "agree" and "strongly agree" were given the same favorable rating. There is no way of reliably gauging the true strength of a student's agreement, so I just want to see for each item what side of the "favorable-unfavorable" spectrum each response falls on. Next, I counted the total favorable, unfavorable, and neutral responses for each entire cluster and subcluster, and divided that by the total number of responses to get a percentage. When I report cluster scores, they will be in the form (x%, y%), where x is the percentage of favorable responses and y the percentage of unfavorable responses. The sum x + y will differ from 100 by the percentage of neutral responses.

In the Fall of 2002, I did this for our professor's first semester course. The matched N was 146. His final results, in tabular format, were:

	pre	post
coherence	(50, 24)	(64, 17)
concepts	(32, 36)	(58, 18)
independence	(51, 30)	(52, 30)

Table 3-1: Fall 2002 MPEX2 results for first-semester UMD reformed introductory course. Data points show (favorable %, unfavorable %) for each cluster.

There were statistically significant gains here in the coherence and concepts cluster, and independence stayed about the same. Another common way to show MPEX results is on a favorable-unfavorable plot (Redish et al. 1998), where an arrow shows the change in a course from pre to post during a semester. In the figure below, the independence cluster change is too small to see, but the other arrows show the coherence and concepts cluster gains.

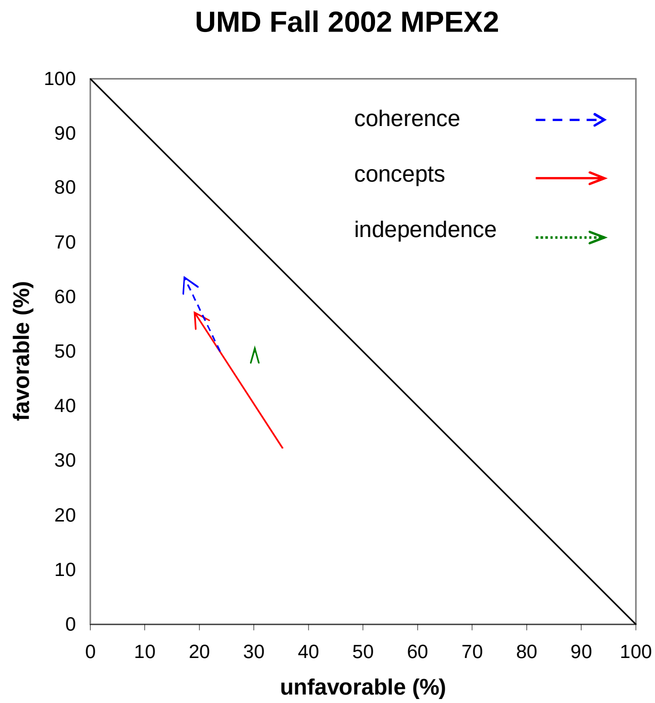

Figure 3-1: MPEX2 results for Fall 2002. The independence arrow is too small to see. The arrow moves from the "pre" score to the "post."

There are many factors that could be at work within this class to cause the gain in scores. Although it is impossible to discern exactly how much credit to give to lectures, interactive lecture demonstrations, homework questions, exam foci, tutorials, or the "course center" (where students discuss homework together), the Maryland PER group certainly acknowledges most of all that the epistemological coherence across various course elements was needed to make this possible.

An interesting modern-physics-related effect

In the spring of 2003, I noticed an interested discrepancy in MPEX2 results obtained from two different lecturers in the second-semester introductory physics class. Both lecturers (Professors A and B) are experienced and tenured faculty in physics education research (PER), and counted epistemological development seriously within their instructional goals. Both professors used tutorials, interactive lecture demonstrations, and personal response systems for quick surveys and interactive problem solving. However, their courses' MPEX2 results differed greatly: Prof. A's students did significantly better in multiple clusters. The rest of this section will discuss this effect as well as possible hypotheses on causes.

A possible conflating factor is that half of the second-semester students took a more traditional first-semester course. Many of these ended up with Prof. B, since Prof. A retained a large number of students from his first-semester class. To control for this factor, I am including in this analysis only those students that had Prof. A for first-semester physics.

Eighty-four students stayed with Prof. A for the entire year, and 24 had Prof. A first semester and switched to Prof. B for their second semester. I will keep the (favorable, unfavorable) percentage format. In the table below, "pre" refers to before the first-semester course, "mid" refers to the post-test of the first semester, and "post" refers to the second-semester post-test:

	A-pre	A-mid	A-post	B-pre	B-mid	B-post
coherence	(51, 22)	(67,15)	(61,17)	(55, 29)	(70, 15)	(76, 11)
concepts	(34, 34)	(62, 16)	(55, 19)	(37, 34)	(62, 19)	(80, 7)
independence	(52, 27)	(54, 29)	(46, 28)	(51, 34)	(55, 30)	(55, 26)

Table 3-2: MPEX2 cluster scores sorted by second-semester PHYS 122 professor. B's students showed statistically better improvement; see Figure 3-3 below.

The most compelling features of this table are in the coherence and concepts clusters. The movement from "pre" to "mid" shows that all of Prof. A's students got significant gains in those clusters in the first semester. However, in the second semester, the students that stayed with Prof. A got losses in those clusters (see also Figure 3-2 below), and those that switched to Prof. B got gains (Figure 3-3). This result cannot be easily explained in terms of selection effects; students who switched to Prof. B because they disliked Prof. A's epistemologically-centered approach to teaching would be *not* be expected to respond especially favorably to Prof. B's continuation of that same approach.

Although I will not report MPEX2 results on individual students, finding cluster gains for individual students allows me to study statistical significance. Using two-tailed, unequal-variance t-tests, I found Professor B got significantly more favorable changes in semester two than Professor A in all categories besides independence ($p = 0.013$ for coherence, $p = 0.002$ for concepts, $p = 0.002$ overall).

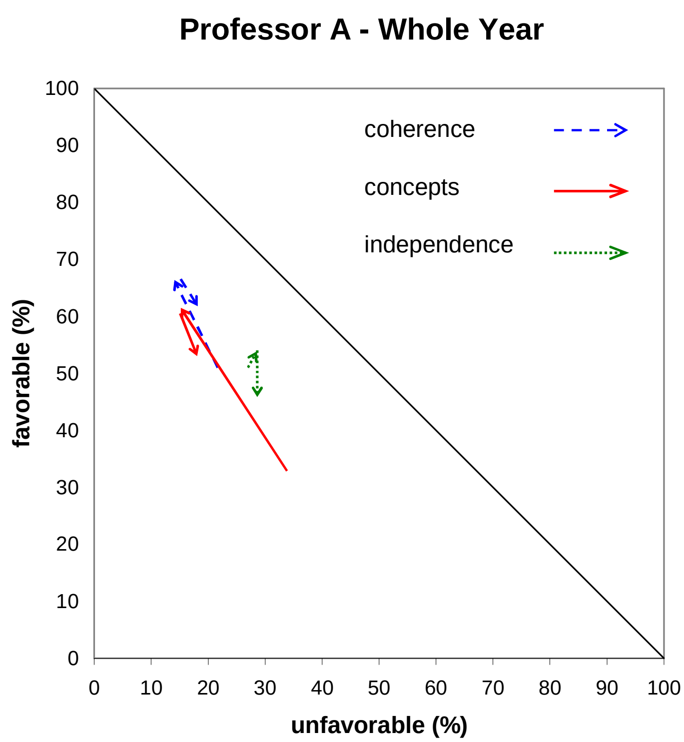

Fig 3-2: A graphical representation of MPEX2 scores for students that stayed with Prof. A for an entire year. See Fig 3-3 for a statistical comparison.

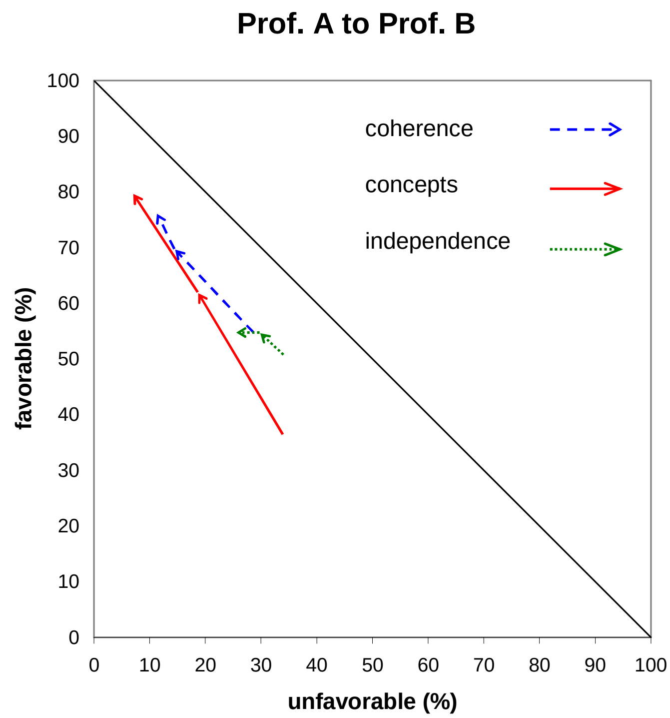

Fig 3-3: MPEX2 scores of students who went from Prof. A (121) to Prof. B (122). Results are significantly better than those in Figure 3-2 in coherence ($p = 0.013$), concepts ($p = 0.002$), and overall ($p = 0.002$)

Why did one reform-minded professor get epistemological gains in the second semester while another got losses? My claim is that Professor A's choice to cover modern physics topics while Professor B did not is part (though not all) of the reason. Why would modern physics cause deteriorations in MPEX2 scores? I hypothesize that modern physics ideas are often hard to reconcile with experience. They can seem like disconnected pieces, especially when compared to previous parts of the course. Students may feel like modern physics ideas are wacky and require acceptance, and not reconciliation or sense-making. It should be mentioned also that for these courses, the post-test MPEX2 was administered right after the quantum unit, providing a point of context that may explain and allow for the transience of the survey losses. The data presented so far, however, do not yet support my claim, because the inclusion of modern physics is not the only way Profs. A and B differed. Prof. A used fairly rigidly structured lectures and PowerPoint slides, and Prof. B did not. Their homework assignments and exams were different, with Prof. A's being slightly more focused on formal quantitative problem solving. Also, Prof. B's class was about 25% smaller overall. Therefore, in order to claim modern physics even partially damages student epistemologies in introductory physics, I must control for some of these conflating factors.

Professor A noticed the difference between his and Prof. B's MPEX2 scores, and was one of the first to hypothesize that his modern physics lectures were partially responsible. His idea for the next academic year, when he again taught the same two-semester sequence, was to eliminate some of the modern physics coverage. He cut the number of lectures in half (to about two), and he eliminated modern physics and quantum mechanics from homework and exams entirely. Even though he added lectures on magnetism, he did have some time to work more carefully on more basic topics that semester. The rest of the course (tutorials, demonstrations, etc.) were very similar from year to year. I looked at his new MPEX2 results.

	A-pre	A-mid	A-post
coherence	(54, 22)	(67,16)	(68,16)
concepts	(33, 36)	(62, 17)	(65, 15)
independence	(53, 25)	(55, 27)	(55, 27)

Table 3-3: Prof. A's 2003-2004 MPEX2 results. This class did significantly better than the prior year in concepts ($p = 0.026$) and marginally better overall ($p = 0.067$)

Graphically, it is hard to see the effect over two semesters, since the mid to post scores changed so little. The compelling result from this table is that the gains in the first semester ("pre" to "mid") are similar to what they were in the previous year, but the post scores did not deteriorate. Comparing the classes statistically, Professor A's 2004 class did better in the concepts cluster ($p = 0.026$) and the overall improvement across all clusters was marginally significant ($p = 0.067$).

What happened? Could Professor A have simply gotten better at fostering epistemological change? The data do not support this explanation; his first semester gains were similar from year to year. Other factors such as class population (courses held at different times of day have different distributions of students) could be conflating, but seeing the similarity from year to year tells me the populations are at least similar with respect to epistemology. In summary, I can say that covering modern physics could at least be partially responsible for worsening epistemological beliefs as measured by MPEX2, either because the topic itself is epistemologically damaging or because covering it leaves less time help students integrate their understanding of earlier, more basic topics. Again, the main support is that when Prof. A reduced the coverage of those topics and kept the rest of the course basically the same, his MPEX2 results improved slightly for the second semester, rather than dropping significantly as they did when he included more modern physics.

Two other professors in Fall 2004

After the professors just mentioned finished their stint teaching our sequence of introductory algebra-based physics classes, two different professors took over. Much of my study with them involved the FCI split task that will be explained in the next chapter. However, I had a brief opportunity to see how their students performed on the MPEX2. The first, who I will call Professor Q here, was getting back into teaching after a hiatus and used Professor A's slides and homework questions. The other, called Professor R, came up with lectures and homework assignments on his own. Both used the same tutorials our PER professors used in previous semesters' discussion sections. I was unable to do a pretest on their students, but I could test approximately half of their PHYS 121 sections at the end of the semester to compare.

Half of each class (N = 78 for Prof. Q and 53 for Prof. R) took the MPEX2. The rest of the class took the split task described in Chapter 4 – I gave whole sections one survey or the other depending on whether the section number was odd or even. The MPEX2 scores (in %favorable, %unfavorable form) ended up very similar:

	Q	R
coherence	(53, 25)	(55, 22)
concepts	(40, 32)	(37, 38)
independence	(44, 35)	(45, 35)

Table 3-4: Post-test results for two different professors' classes on MPEX2. Q's class did not take the pretest, so no comparison of gains was possible.

Most notably, their favorable percentages were never more than three percentage points different, and a swing even to a neutral response from two or three students would account for that difference. Of course, to say that equal ending points implies a similar change during the semester implies similar starting points. We do not have that data for both of these professors. Professor R's class took the MPEX2 as a pretest, and his scores were (52, 26) in coherence, (35, 39) in concepts, and (50, 27) in independence. Combining these scores with all the other pretest scores in the tables above, one can see that pretest scores on the MPEX2 are fairly stable. Across the five samples listed, the spreads are small. All the pretest scores fit within (53 +/-

2, 25 +/- 4) for coherence, (34 +/- 3, 36 +/- 3) for concepts, and (51 +/- 2, 29 +/- 5) for independence, and the highest spreads (coherence unfavorable and independence unfavorable) are largely due to one outer data point. Therefore, I believe I can say two things: (i) pretest scores are stable across different instructors and classes at Maryland and (ii) professors Q and R did not achieve gains on the MPEX2, but they avoided significant losses as well.

Though Professor A apparently got much larger gains in all three clusters (his favorable scores were 68, 65, and 55% respectively on the three clusters), it seems that the MPEX2 is not able to determine whether or if professor Q or R was more effective at forwarding epistemological goals. Their courses were quite different, so it is reasonable to wonder the effect of the differences. However, in the next chapter, I will show how the FCI split task IS able to distinguish between the two classes.

Weaknesses, criticisms, and concerns

The MPEX2 is, for all its potential as an evaluation tool, a crude instrument. I ask students to give simple, unqualified statements (“agree,” etc.) when their epistemological views are sometimes rich and varied even within a response to an individual item, as the validation interviews showed. Students also might not take the survey seriously, especially if they don’t see the value of these instruments for their learning. Although I have done a round of interviews to validate the questions, it may always be possible to find students that misinterpret wordings or give false favorable or unfavorable responses, even after further refinements of the survey.

Despite these weaknesses, I have found interesting results concerning how the MPEX2 evaluates how well courses meet their epistemological goals. I have seen that with the proper reforms, one can achieve substantial gains on the survey, especially in the coherence and concepts clusters. As shown above, I did not get similarly strong results when our introductory course passed on to different professors. Also, the MPEX2 did not indicate much of a difference between two professors with smaller differences in their course implementations. The next chapter will discuss how a modified Force Concept Inventory task *was* able to tell those classes apart with respect to the goal of conceptual reconciliation. As one might guess, the course with reconciliation included as a more explicit goal did better on that instrument. This new instrument is narrower in focus, but that narrowing bought me the ability to evaluate a difference in the courses.

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Chapter 4: The FCI as Modified to Probe Epistemology and Epistemological Development

The majority of this chapter is based on two papers presented at the Physics Education Research Conference, a satellite meeting of the American Association of Physics Teachers. The papers (McCaskey, et al., 2004 and 2005) describe two attempts to modify the Force Concept Inventory (Hestenes, et al 1992; and Halloun, et al, 1995) for epistemological purposes. The first efforts were inspired by a talk by Chinn (2003).

This chapter is centered on two different large-N multiple choice tasks. In the first, I try to tease apart distinctions between student beliefs and answers they believe to be scientifically true. In addition to observing their test-taking behavior, I want to learn if there are gender differences in play and if differences between scientific answers and beliefs are indications of relativism. My second task is to find if modifying the FCI can tell us anything about how different introductory classes reconcile the concepts they have learned.

Introduction

Physics education research has frequently employed conceptual surveys to gauge the effectiveness of curricular advancements. The most frequently used instrument is the Force Concept Inventory (FCI) (Hestenes et al. 1992). The FCI was originally a 29-item multiple choice survey covering Newtonian physics concepts. The authors divide the questions into "force concepts," and they later state that the FCI is best used as a conceptual diagnostic or course evaluation. Despite the popularity of this survey, even today, the years following the initial FCI paper produced concerns about the validity of that instrument. Huffmann and Heller (1995) attempted to invalidate the "concept" groupings through a factor analysis. Hestenes and Halloun (1995) replied, again reinforcing the ways the FCI is useful *on its own* as a predictor of success in physics class and as an evaluator of curriculum success. Like Elby (1999) said about MPEX, one must be careful about making excessively simplistic conclusions based on FCI scores, and that is what this chapter is about.

This dissertation goes farther than the initial debate between Hestenes, Halloun, and others. Sure, a physics student can give an answer to an FCI item that reveals something about his or her physical thinking, but what kind of insight are we really getting? The work of Chinn & Samarapungavan (2001) contains a relevant anecdote. A science teacher overhears her fifth-grade students talking about a molecules test they had just completed. One asks another, "Do you really believe that stuff about molecules?" The second student replies, "No way!" Another relevant inspiration came to me just before starting graduate school at the University of Maryland. I attended an informal talk by Eric Mazur, and in it, he related anecdotes similar to some in his *Peer Instruction* book (Mazur 1997). He was giving FCI questions to his class, and one of his students asked, "Should I answer these questions the way I think about them, or the way you taught us?"

It is entirely feasible that even adult physics students approach our courses with the same mindset that the molecule-discussing fifth-graders did. Physics is often full of counterintuitive concepts, and it's easy for students to brush something off or simply "accept" it rather than understand it. This is the sense in which this dissertation challenges previous FCI work. Why should anyone bother debating how factor analysis affects how one views FCI scores or what this instrument can be used for if students can give answers (correct or incorrect) that they neither understand nor believe? This question led my colleagues and me to wonder: is there any way of modifying FCI instructions so the answers are meaningful in both an epistemological sense and a conceptual sense? One practical use of this new survey methodology is that it gives epistemological information through a conceptual lens using one of the classic large-N survey instruments from the literature. I would argue that physics instructors might deem my FCI split research more pressing and relevant than the MPEX instrument since MPEX lacks connections to specific physics concepts.

After investigating the answer-versus-belief question, I further narrowed the scope of my FCI research. I formulated my research question more epistemologically: do the answers our students give tell us anything about which answers (correct or not) make the most *intuitive sense* to them (whatever they choose to mean by the term “intuitive sense”)? I would like to see two things here from students: an epistemological belief that correct physics content is reconcilable with their common sense and everyday experiences and the conceptual understanding needed to make that reconciliation happen. For the traditional FCI, two students can have similar scores but different epistemological outcomes if one feels the FCI answers she gave make intuitive sense and the other does not.

Two major FCI revisions will be discussed. In the first, I gave unmodified FCI questions new marking instructions. Students were directed to mark one answer choice the one they “really believe” and one choice as the one “they think scientists would give." Students could mark the same choice for any number of the questions. The wording assumes that the students do not think scientists might give the same wrong answers as they. No indications appeared in the interviews that contradicted this assumption, but it is still possible for students to realize scientists (such as non-physicists) may be capable of wrong answers. I gathered data from two institutions (the University of Maryland and Davidson College), and conducted validation interviews to help interpret the results. Data from those interviews were used to conduct the second round of modifications. The modifications centered on the "answer you really believe" instruction: I found many students treated that as a prompt to give an intuitive answer. Since I had learned important things about gender differences and relativism, and we frequently saw nods to intuition in the interview data (but not always uniformly or explicitly), I took the opportunity to make the task more explicitly epistemological and probe intuitions versus scientist answers directly. This would allow me to investigate whether students felt science and intuition were reconcilable – an interesting epistemological question

The second iteration of new FCI instructions reflected this inspiration. Instead of circling the answer they "really believe," the students were asked to circle the answer that made the most intuitive sense to them. A round of interviews followed this set of testing as well.

Original FCI task study

Populations and survey task

My initial study used three populations of introductory physics students. Two were from the University of Maryland. The first group was about to take the first semester of the introductory algebra-based physics sequence (PHYS 121). This course, taught by faculty experienced in PER, used research-based tutorials and labs consistent with that field. The second group was starting the second course in the algebra-based sequence (PHYS 122). All of them had taken PHYS 121 in a recent semester, and most of them took a traditional version of that course. My third group was from a traditional introductory physics course at Davidson College (DC), a small and highly selective liberal arts college.

The FCI task I gave consisted of two parts. At Maryland, students took the test in the standard way (marking answers on an optically scanned sheet). When finished with the instrument, those students handed in their answer sheets and were given instructions for the second part. These read:

> We'd now like you to take the Force Concept Inventory a second time. But this time, the instructions are a little different. First, write your name on the top of the test just as you bubbled it in on your scantron sheet. For each test item:
>
> - Please **circle** the answer **you really believe**.
> - Please draw a **square** around the answer **you think scientists would give.**
>
> Here's an example of how to mark your test.
>
> (A) Answer I really believe.
> (B) Some random answer.
> $\boxed{\text{(C)}}$ Answer I think scientists would give.
> (D) Another random answer.
> (E) Yet another random answer.
>
> If the answer you really believe agrees with the answer you think scientists would give, draw a circle and square around that same answer.

Students at Davidson had a slightly different procedure with the same essence. They wrote their answers (for the first pass, squares, and circles) on separate sheets of paper by hand. Also, their first pass instructions lacked the phrase "Avoid guessing. Your answers should reflect what ***you*** personally think." Maryland's first pass included that line.

Data, analysis, and discussion

I scored student surveys in several ways. Students were separated by gender to see if each would get different averages. The first pass (called "1"), the circled "beliefs" (B), and the squared "scientist answers" (SA) were compared with the FCI answer key, and I recorded the number correct. Also, I counted the number of answer splits each student gave. A *split* is any item where the belief and scientist answers disagree (and neither is a blank). Finally, I checked which answer (B or SA) agreed with the first pass. That way, I could see which choice would be the most likely thing a student would present as a test response. I had to be careful with the Maryland data because students often misinterpreted the instructions. Specifically, they would skip entire items or mark only a circle or square. I removed a student's data from the sample if he or she left five or more blank responses. I considered any missing answers on the first survey pass or any missing square or circle on the second task a blank. A future version of this survey simplified matters by removing the first pass and further insisting on separate markings.

For my first study, I was interested in doing a gender comparison. Belenky et al. (1986) indicated that women had a "connected" view of knowledge. One can formulate two opposite potential outcomes for women on the split task. If they see physics as fitting into a "separate knowledge" view, they might be more aware of when physics content does not seem to mesh with their common experience. Their honesty about this experience could lead to more splits. Alternatively, their *desire* to see physics as connected could lead them to try and reconcile, producing lower split rates. Hammer (1989) argued that finding and maintaining a "connected" stance is very difficult in an introductory physics class, though, so my first story (with more splits) is more plausible.

The counts for the first semester Maryland class (PHYS 121) are as follows. Scores are averages out of 30 possible points.

	Males	Females	Totals
N	59	57	116
1 score	13.7	8.6	11.2
B score	12.7	7.8	10.3
SA score	13.2	8.6	10.9
1-B splits	5.9	6.8	6.3
1-SA splits	7.2	10.3	8.7
B-SA splits	5.5	8.5	7.0
… with 1 = B	2.8	5.4	4.1
… with 1 = SA	1.6	1.9	1.7

Table 4-1: FCI and split pretest scores for males and females in the PER-reformed PHYS 121 class. Both SA score ($p = 0.006$) and gender ($p = 0.007$) correlate with B-SA splits when modeled alone, but each is marginally significant in an ANOVA modeling both together. For males, SA score correlates with splits ($p = 0.046$), but for women SA score does not correlate with splits ($p = 0.80$).

As far as pure scores go, it is worth noticing that there is a gender gap in the course. The males got about five additional questions right on all passes on average. Both genders scored better with their "scientist" answers. Both genders split a fair amount, but women split somewhat more frequently. Also, in the PHYS 121 class, the "belief" answer agreed with the first pass for females 63% of the time, compared with 51% for the males. One possible explanation for women splitting more is that gender and score are conflating factors. An analysis of variance (ANOVA) on the data shows that individually, both FCI "scientist answer" score ($F = 7.9$, $p = 0.006$) and gender ($F = 7.6$, $p = 0.007$) significantly correlate with splitting (women or low scorers split more). Furthermore, when both score and gender are included in the ANOVA model, the two factors together significantly predict splits, but score alone ($F = 3.33$, $p = 0.071$) and gender alone ($F = 3.10$, $p = 0.081$) are only marginally statistically significant. One can check by breaking down the data further whether score predicts splitting behavior for each gender individually. For men, score did significantly correlate with splits ($p = 0.046$), but for women it did not ($p = 0.80$). Therefore, it is unclear whether there is a significant gender effect in splitting on this task.

Epistemologically speaking, though, I am most concerned with the splits between belief and scientist answers. In my subsequent analyses, I was then careful to examine what a split means and adjust the task accordingly. One can notice a strange occurrence in the data – the first pass sometimes did not agree with *either* the B or SA choices (on average, about once per test – note that the last two rows do not add up to the number of splits). I do not know specifically what caused these occurrences.

Here are the data for the PHYS 122 course, taken after the material tested was covered. This is "post" 121 material, and students here could have had reformed or traditional instruction for that course.

	Males	Females	Totals
N	20	30	50
1 score	17.2	11.3	13.7
B score	16.5	10.8	13.1
SA score	16.4	11.8	13.6
1-B splits	3.6	3.9	3.8
1-SA splits	5	9	7.4
B-SA splits	3.9	8	6.4
… with 1 = B	2.5	6.3	4.8
… with 1 = SA	1.2	1.3	1.3

Table 4-2: FCI and split scores for males and females in the PHYS 122 class (taken after the FCI material was taught)

The DC data are in the following table:

	Males	Females	Totals
N	11	9	20
1 score	20.9	19.8	20.4
B score	21.1	16.8	19.2
SA score	21.3	20.6	21.0
1-B splits	2.9	5.4	4.0
1-SA splits	2.5	3.6	3.0
B-SA splits	1.6	5.1	3.2
… with 1 = B	0.5	1.7	1.0
… with 1 = SA	1.0	3.2	2.0

Table 4-3: FCI and split scores for males and females in the DC class. Data are from after a semester of instruction.

At the time of this initial study, I was interested not only in epistemological issues but also gender differences between classes. Indeed, gender differences might be studied with surveys such as the MPEX2, although I did not perform those analyses. The main gender difference in the data above (aside from the gap in score averages) is in the number of splits.

Of course, at this point it remained to be seen (as stated in our second paper on this subject) what a split meant exactly. Interviews discussed below indicated to me that a new interesting angle would be to use a split task to study how well the students are reconciling information covered in the FCI. This reconciliation angle forms much of the direction my FCI study took after this round of surveying. Put another way, I decided to start worrying less about whether students *believe* the answers they are putting down on an FCI, but rather whether students have *reconciled* correct scientist answers with their own common sense.

I still gained rich epistemological information from my original survey. The Davidson College study gave a space for students to leave comments while performing their FCI tasks. Many students seemed confused about why they would ever separate their belief and scientist answers. One sample response read as follows:

> "OK, I'm a little confused about the purpose of this. My answers the second go around won't be any different than my answers the first time. Even if my answers are wrong, I wrote them believing that scientists or anyone else for that matter would give the same answer."

Of course, I do not want to confuse a student with a survey, but this type of "confusion" is epistemological and of great interest to me.

Another aspect of my analysis involved looking at specific clusters of questions. Specifically, I am interested in FCI questions dealing with Newton's Third Law (N3). I feel N3 is a counterintuitive concept that might lead to a lot of splitting (and I believe this for both versions of this task). The N3 items on the FCI are written such that students are unlikely to square (SA) the correct answer unless they learned about the scientifically-accepted answer in class. For the Maryland PHYS 121 data, 46 students got at least two of the four N3 questions right on the SA pass. Of these, only 16 (35%) of the students did not have splits on those four questions. Among the fifteen students that got all of the N3 items "right" for their SA, only three had no splits. My preliminary conclusion from this result was that people who "get" (as far as a test can say) concepts like N3 might not really believe them.

This study inspired several follow up questions. Most importantly, what does a "split" on this survey actually mean? This is a validity issue; I need to establish that this survey's splits tell us meaningful things. Before I settle that, though, consider these questions: To what extent do high and low splitters think it is possible and valuable to *resolve* discrepancies between their own ideas and the scientifically-accepted answers? How can one use reconciliation data in general and split data in particular to look at different courses and evaluate how they meet or fail to meet their epistemological goals?

Follow-up interviews, relativism evidence, and discussion

I performed follow-up interviews to get at what a split on this task meant. Also, I wanted to figure out whether I could learn anything about the epistemological beliefs of people who split often (high-splitters) and rarely (low-splitters). One of my speculations was that low-splitters were resistant to bringing their own ideas to a test or are otherwise authority-driven. Also, perhaps the high-splitters might be epistemological relativists that do not feel the need to reconcile competing ideas, as literature from Perry (1970) on forward notes. I interviewed nine PHYS 121 students for a half hour each. I was interested in both ends of the splitting spectrum. It turned out that none of my initial speculations applied to any of the subjects.

My interview protocol started with the following questions:

- What is your major/year in school?
- Why are you taking this course?
- Had you had physics in high school?
- If so, do you feel you got a lot out of that class?
- How do you know someone is an expert?
- What do you do when experts disagree?
- How do you know when you understand something?

The last three items, designed to get at my gender-related questions about splits, are epistemologically-centered questions from Belenky, et al (1986). After those, I followed up with specific questions about the task. The first question listed here was given to everyone. I asked the later questions to the high-splitters only.

- Here was the task we gave. Before going into it, did it seem to make sense that we were asking you to do this? Why or why not?
- Why do you believe the answer you circled?
- Why do you think a scientist would give the square answer?
- Is it worrisome to you that there's a difference?
- Do you think the scientist could be convinced to see your point of view? If so, how?
- Do you think you could be convinced of the scientist view? If so, how?

Several patterns emerged from the transcripts. The low splitters I interviewed typically did not think my task made much sense. Many gave answers in the interview similar to the comment written to me by the DC student above. One example came from a student codenamed "Sarah" (all names in this section are pseudonyms).

> "The only thing I didn't like was that every time I thought an answer would be right, I figured that's what a scientist would say too, so a lot of them ended up being a circle and square around the same one."

I expected responses like this. However, I was more interested in figuring out what a split actually meant. I had hoped that splits indicate real differences between the student's belief and the answers he thought to be scientifically correct. Of course, the interviews showed me more than I bargained for. Splits would sometimes correspond to instances where the student did not have confidence in her belief. "Emily" expresses this as follows:

> "…for the ones where my circle and square were on different choices, I thought maybe it was just my intuition-based answer, so then a scientist might say something different because it wouldn't… they would be basing their answer on… facts, I guess."

Emily seems to believe here that scientist answers are based on "facts" and intuitions are not. So her statement here implies both a specific lack of confidence in her intuition and a belief that she lacks essential relevant facts on which to base her answers. "Christine" gave a statement putting the disconnect between scientific facts and intuition even more succinctly:

> "It is true, if you listen to a scientist talk, a lot of times, you don't understand everything, and so if I didn't understand everything in the answer, it seemed like a plausible scientist explanation."

Absent from Christine's beliefs (as articulated in the interview) was any notion that scientific answers can contain words or jargon that precisely express in technical terms ideas within the purview of common sense. She may still believe that jargon-filled statements could make intuitive sense to scientists, however.

One generic idea I was on the lookout for was any inkling of multiplicity, meaning a view that somehow multiple answers can be scientifically valid or true. To get at this question, I will include here the student responses from my interviews to questions like, "Is it worrisome to you that there's a difference?" I am presenting data from each student because there is a small enough sample that showing this data is feasible. Also, this will allow the reader to evaluate my analysis directly rather than trusting a less transparent coding scheme. Of course, the quotes already presented are from the same interviews, but a more complete picture of the data is needed if I am to claim anything about what splits mean. I will also be looking at their responses to the expertise question to see if I can get at their views on expertise with respect to science and other fields.

Christine (already quoted above) was a junior marine biology and psychology major whose high school offered a special honors physics program in her freshman year. She believed that credentials or certification is the best way to define an expert, but acknowledged in the context of court cases that experts can disagree on something. I probed further (I represents the interviewer, S the student):

> I: So, you've got two experts, and presumably they're both credentialed, and they've gotten a lot of practice doing the sort of thing they do there, they're used to trying to talk to you so that you follow what they're saying. What do you do when two of them disagree?
> S: Personally? Like, what would I decide?
> I: Yeah.
> S: I guess it would just be what makes… you can be an expert, but then you can look at the data or whatever you're looking at in two different ways and come to different conclusions or the same conclusion, so I guess it could be whatever followed more along my lines of thinking, I would have an easier time believing what they were saying.

So, while admitting that experts can come to different conclusions, she does think that one of them for whatever reason would be easier to agree with. Although her criteria for agreement are not well articulated, she has some way of judging between competing expert testimonies. On one of the Newton's Third Law questions, she split, and I asked her about it:

> I: Now, the first question was, you have a truck ramming into a car… was exactly the same kind of thing. [uh huh] Did you or your whole group predict that one of the forces would be bigger than the other?
> S: Uh huh.
> I: Basically going along with this (points to one of the answer choices) [yeah] the truck exerts more? Ok. And you all saw that, right?
> S: Yeah, we all went through it.
> I: Then you saw the demonstration that they were the same.
> S: Oh yeah… the springs…
> I: Was it worrisome to you that there was a difference between the two?
> S: I mean, at first, it didn't make sense, when we were all trying to figure out how to, you know, explain it to ourselves and make it make sense in our own head when the truck's so much bigger than everything else, but once we worked through the problems and used the

equations to see it and realized that we need to look at force and the change in velocity as completely separate things…
I: OK. So, just looking back on this, you kind of picked choice A because…
S: My raw intuition said that's the one that made sense to me.

This is evidence that the split was a discrepancy between intuition and a science answer, and that her group wanted to be able to explain it to themselves in going through the relevant tutorial problems. The desire to figure it out is the only way the split was truly "bothersome." In summary, there is no indication here that Christina thinks two different answers can both be right.

Emily (also quoted above) was a junior neurobiology and physiology major who was taking the course for a premed requirement. She had the following view on expertise:

I: Have you ever seen experts disagreeing?
S: Yeah.
I: Give an example?
S: (pause) Let's see. Right off the top of my head… I guess in biology, there's different, like, let's see, if there's some sort of theory put down, and you think that they're an expert, and a couple years later, a different experiment is done to kind of nullify that experiment saying no, this is what's really going on… at one point you would have thought he was an expert because…
I: So, let me get this straight, the person that came out with the first result [mmmhmm] is discredited later [yeah?], is the first person no longer an expert?
S: Um… no, they… in their field I wouldn't call them not an expert, but maybe in that specific experiment, they are no longer an expert because the results, I guess, didn't hold up in the long run.
I: So, how is this discrediting process done? I mean, you say you have two experts disagreeing, suppose another person comes around and disagrees with the first result from a while ago, for whatever reason. How do you decide that that's right and the first one wasn't right?
S: I guess the more evidence, the more facts that you can support the experiment, in this case, since we're talking about an experiment, if they hold up in the long one, then I'm gonna be more prone to believing the person that has the better data, I guess.
I: So you're making a judgement about whatever data they give you?
S: Yes, and if they can apply, if their discussion on the results holds up, I mean, I'm not gonna just accept data, whatever they say…
I: All right. If you didn't come up with one off the top of your head, I mean, you did for biology, I'm glad we were able to talk about that… the one I would have suggested was you have experts or so called experts in politics disagreeing on things. How do you decide… what do you do when two experts in that field disagree? I'm just asking this because it's come up in a lot of previous discussion.
S: Um, let's see… like a certain topic?

I: Um, do you want a specific one? There were a lot of experts on TV disagreeing whether the war in Iraq…
S: Was OK or not? OK. Um, I guess you just have to, um… I'm not saying… I don't think either one was nullified in their expertise [uh huh], but what I guess I would look for… facts from both and then kind of decide for myself which one I agree with. But I think they're both experts.

Like Christine's interview, Emily acknowledges that experts can disagree, but she can still determine which view aligns best with her beliefs. As to her splits, she made her views clear in her quote above. When asked if a specific split between two choices D and E on a centripetal motion problem was worrisome, the dialogue (from an interview on October 15, 2003 – about six weeks into the semester) went as follows:

I: Is it worrisome to you at all that this conflict exists?
S: Yeah. (laughs)
I: So, what would it take? Do you think… do you think you could argue, you could effectively argue your case for choice D?
S: Um, I would think so. I think that from what… how this course has been going so far, how I've been reconciling, I guess, these differences [uhhuh], definitely through the tutorials, because I'm seeing it in an experience that I can relate to, because just like putting letters on paper, it's… I kinda I guess get confused with what is really going on. And also by experiments he's done in class and things like that, so… I might be able to argue my points now, but I don't know… if they'd be the correct points to argue.
I: You're not sure if they're right?
S: Yeah.
I: So, conversely, do you think there's some way that an expert through a tutorial or lecture [yeah] could convince you of E? OK. You'll be dealing with this pretty soon in a couple of weeks, to work it out. [OK.] It's a quick thing.
S: He's like (referring to me), "it's really easy, you're just…" Sometimes I really just feel dumb in physics.

Again, it boils down to confidence. She does not feel her circled answers are worth arguing if they conflict with an expert answer, hence her feeling of dumbness in physics.

My next student, Jackie, was a junior biology and premed major, and like many other PHYS 121 students, she took the class for a premed requirement. She had an interesting view on expertise that distinguished between scientific and political contexts:

I: All right. I'm trying to think which of these is the best to ask… have you ever been in a situation where you've seen two experts disagreeing on something?
S: Yeah.
I: Like what?
S: Like a lot of stuff in government, I mean, you have so many different sides.
I: Political issues? [yeah] OK. So, how do you come to a decision as to which is right when two experts disagree?
S: I guess it's more… with government issues and stuff… with your personal opinion.
I: So you pick whichever…
S: Yeah, if you can…
I: Whichever side agrees more with your personal opinion?
S: Yeah.
I: OK. I don't know your group dynamic, maybe I should, I guess I've seen you, but do you have a lot of disagreements with your other group members when you're doing tutorials?
S: Um, sometimes.
I: OK. Is it a question then of… going with whichever side is your belief?
S: Um… (pause) well, I guess, I mean, in tutorial, we kind of argue it through. Everyone brings up points that maybe I hadn't thought about, so…
I: OK. Would that be applicable in the government situation, or in talking about politics and government, or is that too different?
S: I think it's a little different. A lot of those issues are personal, where physics is kind of your understanding of the concepts.

Clearly the contexts are different. While Jackie may believe two political experts can have different opinions, the same would not apply to physics because there conceptual disagreements must be "argued through." Anyone who watches political debates would agree that does not happen much in that arena.

On the subject of splits being bothersome, Jackie had differing views. On an early question concerning an object accelerating with gravity, she showed some rare (for my subjects) confidence in her answer:

I: So, given the lesson you've had now, there would be a circle around C and a square around B. Do you think… so, there's a difference. Is it worrisome to you at all that there's a difference between the two answers, or not?
S: What do you mean, worrisome?
I: Um, well, let me put it this way, if you just had this to take as a test that counted for something, which one of those would you mark? If you only had one mark of the pencil…
S: Probably C.
I: Probably C. Would it bother you then, that you had this idea that physicists might say B?
S: I guess… a little bit. (pause) I don't think it would bother me that much. I guess I'm pretty set on C.

Her scientist answer came from her belief that gravity changes with altitude, which is technically correct. However, their recent tutorial had just assumed as the course generally does that gravitational acceleration is constant, so her conviction behind her circle response is appropriate. A later question on the motion of a ball leaving a circular track, though, led to a much more drastic split and a different response. Choice A indicates that a ball will continue in a circular path even though the circular restraining track ends. Choice C indicates the ball will move outward.

> I: Is that worrisome that there's a difference, possibly, between the two?
> S: Yeah, cause they're really different (laughs).
> I: They're really different this time. OK. Do you think… which order should I do this. Your point of view is going like this, that it would complete the circle. Do you think you could convince the rest of your group or possibly your tutorial instructor that the ball would do this?
> S: No. [laughs, pause] Um, I mean, like, the object in motion likes to stay in motion, an object going 35 miles per hour wants to stay 35 miles even if something stops… if you turn the car, or whatever. It kinda follows along the same lines… something going in a motion, a circular motion's gonna want to keep going in that motion even after it's… path is discontinued.
> I: So, you see the circular motion as being… sort of an application of Newton's first law, that's the one you were quoting, that objects tend to remain in the state of motion they're in.
> S: Yeah.
> I: And this is in the state of motion that…
> S: The track was… yeah.
> I: OK. Which of these choices, A or C, do you think you would prefer if you only had one on a test?
> S: Well, I mean at this point, probably A, just because I can try and explain it with stuff I already learned. In the case of C, I don't really know how centripetal forces really apply to stuff yet.
> I: Ok, so… you haven't seen this yet, but maybe you will down the road. How do you think you'll settle this later?
> S: How will I settle it later? (pause) I don't know. I mean, C kind of makes sense because it is still kind of trying to go toward the center, but it curves outward, so it kind of (pause) yeah… I don't know.

The difference here is that she seems more bothered by the split. This time (see the second line), she indicates that the answers are *really* different, as opposed to the previous clip where the circle and square choices were more similar. If she really did see her gravitation circle and square options as different, her split would look like relativism.

My next student, Laurie, was a senior wildlife management major. That major requires the mechanics introductory course, but not the subsequent one on electricity and magnetism. She felt like the course was going horribly and that she would fail if she did not find a tutor or something similar. When asked about experts disagreeing, she brought up an interesting context from her personal experience:

> I: Say… OK. Say the right stuff. Have you ever seen an instance of experts disagreeing on something?
> (pause)
> S: Um, police officers?
> I: OK, in what way might they disagree on something? What do you consider police officers an expert at?
> S: Well, I used to work security, so I was in court with police.
> I: Uh huh
> S: And the police always had to take the stand.
> I: Uh huh
> S: And the attorney and the police were always disagreeing.
> I: Oh, so…
> S: and they're both experts really.
> I: Oh they're…
> S: at law
> I: They're experts in the field of law, somehow?
> S: Right.
> I: OK, so how do you settle it? We'll say you had to be on a jury, let's say, and you have two people that you see as experts, what do you do when they disagree, then?
> S: Look at all the evidence.
> I: OK.
> S: I would go with the cop, though, cause that's what we hired him for. The attorney is trying to win the case for the criminal.
> I: So, the attorney in the case, you're talking about the defense attorney questioning the police officer, and you question the defense attorney's motives in that case. Does that sort of taint their expertise? That's the impression I'm getting from what you're saying.
> S: Yeah.

Like others who have discussed experts disagreeing, she briefly nods to evidence but also feels like police have a natural credibility in cases like this. In science, perhaps she would say that two scientists would be on similar footing until evidence came out one way or the other. On the split task, she had a view similar to Emily, noting that "I'll put a circle around the one that makes sense to me and a square around the one that was more technically termed, and I wasn't sure what it meant." A key point in my interview where I asked about a split concerned a circular motion question with an object whirled in a circle by a piece of string. If you cut the string, the object will fly straight (answer B), but many students give answer A, like Laurie did for her circle answer:

> S: Because… (pause), because they would say there's nothing making it go the same direction. It just seems logical to me, because the velocity is going in a circle, it would go to A. But I think a scientist would say B, because there's nothing making it go in a circle, except for when you're swinging it, but when the string broke, it would just fly off… so B.
> I: OK, all right. That sounds like an explanation that a scientist might potentially give. Now, is it worrisome to you at all there's a difference between these two answers? That you believe one, and you think…
> S: Yeah, I just wanna know which one's right.
> I: OK. How might you… how might you sort out then which one is right?
> S: Conduct the experiment.
> I: OK. That's one way of doing it. The experiment is a little bit hard to conduct, because it's hard… it's hard to swing a rope above your head and break it at one specific point, cause the break has to be completely instantaneous, it depends on what you're using to break it. I would never do this in a class, but let's say hypothetically myself as a TA or a professor were to just tell you B is right. Would that fix everything for you or not?
> S: Mmm-hmm. Yeah.
> I: Why?
> S: Because I can understand why B could be right.
> I: OK, would you be willing to throw out…
> S: A?
> I: Yeah. Are you comfortable doing that?
> S: No…
> I: OK.
> S: Cause it just seems logical, but I've learned in this class… I dunno.
> I: No, go on.
> S: I've just learned in this class that everything I think is right is wrong. So I believe B.

She has learned to distrust her intuitions so much that she is ready to learn either from authority or experiment what the right answer is, and to her, there is one clear right answer she simply does not know at this point. Before moving on to the last three people quoted, let me summarize. These three students are committed to there being one right answer in physics although they see how experts in other topics can disagree for various reasons. There is no evidence that the students believe there is only one way to explain a certain correct answer, but the main reason splits bother them is because they know there can only be ONE correct answer on the FCI.

Leila was another junior physiology/neurobiology major that was in the premed program. Having just taken a more difficult organic chemistry class, entering a physics class that was more conceptually focused was a relief for her. Her response to my expertise question is similar to others; mentioning that physics expertise is different than other expertise and technicality plays a big part:

> I: OK, so you didn't have physics. So, now, sort of away from the physics class track of questions, how do you tell or judge if someone is an expert at something? Doesn't have to be physics.
> S: (pause) Um, how do you judge if somebody's an expert [mmm-hmm] at something? Usually they let you know that through their, like, they'll seem very knowledgeable, so if you ask them a question, they'll give you a nice, detailed, *friendly* answer, like something you'll actually… It won't be…
> I: Friendly in what way?
> S: There's two ways, because somebody can give you this answer to a question, or can fill you on some things that they're an expert in.
> I: Uh huh
> S: through these big words, specific jargon that they use, and then you think, oh wow, they must know what they're talking about *or* a really good person will tell you the same stuff but in layman's language, and you'll be able to maybe connect with them in that sense, and I think that probably shows somebody who's more of an expert in what they do.
> I: So you prefer the latter of those descriptions a little better, rather than someone…
> S: Yeah, although the first one will seem really magnificent, but in a very strange way, like, you know, distant, like, oh wow, he must know what he's talking about, but, you know, I don't.
> I: I'll never want to talk about that over dinner with him or her, or whatever.
> S: That's right.
> I: OK. What do you do in cases if you've got two experts on television or if you're talking to them in person and they disagree on something? Right, if you have these two people, suppose they're very well practiced, we'll even use the definition that you like, that they're both used to talking to people in sort of layman's terms, but they're disagreeing on something, how do you sort that out?
> S: Am I trying to form my own opinion?
> I: Um, I suppose, let's say you're trying to evaluate for yourself which of… yeah, basically you're right, which one of the opinions to
> S: adopt
> I: adopt, if they disagree.
> S: Well, if they're disagreeing, I would, you know, mentally outline their points or something and try and see which one I agree more with, so it would just be personal.
> I: OK.
> S: Which one is more tailored to… well, see, it depends on what the field is, but if it's something like physics, I have no clue, but if it's something like where values and stuff are…
> I: ethical or political, maybe?
> S: Yeah, so I guess I'd be inclined to kind of, according to my values, my background, my… everything.
> I: It would be a match against yours… but physics just seems different to you?
> S: Yeah

She went on to assert that physicists can disagree, and they might on things like, say, string theory, but she could not understand the resolution.

Leila's split on a question (FCI #4) covering Newton's Third Law split is very consistent with others I have shown so far. In it, choice E represents the correct answer: a car and truck exert equal forces on each other when they collide. She circled a more intuitive response and squared the correct answer:

> I: This question here. Car and truck. A large truck collides head-on with a small compact car. This is what we did in the tutorial. [mmmhmm] So, you're supposed to pick which of the forces you think is right, so, can you… you circle "the truck exerts a greater amount of the force than the car exerts on the truck" and you square "the forces are the same." So, why did you do that? Why did you decide to circle this one?
> S: Because that's what I *thought*, and that's what I thought up until the tutorial.
> I: Until the tutorial, that's fine. So, what was attractive about answer E that made you square it at the time, do you remember?
> S: Because it seemed like that was something a physicist would say, like, it just seemed so… well, let's see. It was the car exerts a greater amount of force, that wasn't anything. Neither of them… you know, neither of them… this is dumb. Neither of them gets smashed, or the car gets smashed cause it's in the way of the truck? No.
> I: Mmm-hmm.
> S: The truck exerts… the car doesn't exert a force on the truck, that's not right. Like, there would seem to be. So, this one seemed like the runner up to my initial feeling, and it seemed like, ok, this is something that, you know, a professor or somebody with a whole lot of knowledge would say, it just seemed like one of those quirky things about physics and sciences, you know. It's totally what you don't expect, so…
> I: So, you expect the physics answer to be something you don't quite get at first, and it's a little quirky looking, so you put… all right. Is this worrisome to you, like if you were to do a survey like this and you had the impression that there could be these two answers, does it bother you at all that there's a difference?
> S: Well, I guess it's a problem when you're taking a multiple choice test, you know, you're sometimes stuck on two different answers, and it's worrisome there which one is right.
> I: Mmmhmm
> S: And then, you're supposed to be the expert, so you're supposed to know the right answer, not what you think versus what the real expert thinks.

She clearly says that such a split is bothersome on a multiple choice test. However, since she indicated in the interview (using a less dismissive variant of the "language manipulation" reconciling I will show a student doing frequently in Chapter 5) that she was able to reconcile it, the concern was not serious. There are also (for example, when she says at the end here that “it’s worrisome there which one is right”) that she always talks in terms of there being only one right answer.

Sarah (already quoted briefly above) was a junior majoring in biology and secondary education, with the goal of teaching biology in high school. She pointed out a popular perception of expertise among students, but did not articulate much beyond what I have shown already about what to do when experts disagree:

> I: OK, something not related to physics, you can answer this in any way you want, but… when you think of someone as an expert in something, how do you know that someone is an expert?
> S: When I think of somebody as an expert, I think of somebody who has a lot of knowledge pertaining to the subject that they’re an expert in, but who also can teach that knowledge to other people, you know, so that they learn very well, and to also… pretty much that.
> I: OK, so, being able to explain what they know is an essential part of it?
> S: Yes.
> I: OK. So, the next thing… this doesn’t happen as often in early physics classes, because physics professors often agree on things, but sometimes experts… two that are in the same field, will disagree about something, and each in a debate would try to convince you that what they do is right. What do you do when experts disagree? Have you come across this situation recently?
> S: No, I’ve never been in that exact situation, but if I were one of the experts disagreeing with, say, you on the subject, I would want to talk it out, you know, and hear what your viewpoint is versus mine, and then try to work it out and see which is the correct one.

She also agreed with others above with regards to how to answer questions on a test:

> I: Well, I guess that would be another question I’d ask you, then. If I were to ask you on this, pick an answer you believe… which of those strategies would you be more inclined to take? Would you prefer to answer what you’re learning, or prefer to answer your common sense?
> S: I would probably prefer to answer what I was learning.
> I: OK, why do you prefer that?
> S: Because at least with what I’m learning, I know what’s correct and what’s not, (did I even?) understand why things happen. What I’ve learned so far is that my common sense can be wrong! So, you know… what you think would happen doesn’t all the time.

In response to whether splits were worrisome, she added:

> “Well, just because then I wouldn’t know which was correct, or anything, and I’d wanna know which one was, you know? There can’t be two different answers. Well, I know that… I know that there’s two different ways… if you can explain things and support your answers, I know there can be two different answers, but I would prefer to be saying the same thing.”

This is the closest I got to seeing someone say that there can be two different answers, but Sarah’s implication is that this difference would bother her and she would like to figure out which is right. Her discussion of "two different ways" points to her belief in the existence of multiple *explanations* rather than multiple answers, as does her statement that "there can't be two different answers."

My last subject is the only male who volunteered for these interviews. Todd was a junior biology and psychology major in the premed program. He enjoyed his high school physics class, especially in the mechanics portions. His definition of expertise is a standard one learned in psychology class of anyone who works in their field for ten years. Like others already interviewed, he brought up politics in contrast with physics:

> I: OK. So, you gave me this definition, that, I mean, you've come up with one for yourself for what an expert is. Have you ever seen experts disagreeing on something?
> S: Mmmhmm.
> I: OK, like what?
> S: Um, I think years ago, what is it? Something about quantum physics… do quarks have mass, or… something that's not supposed to have mass.
> I: Neutrinos, possibly?
> S: Yeah, neutrinos, if they have mass or not. It's just more information or it's just a different interpretation of the same information.
> I: OK, so what would you do in that case, if you were dealing with two experts giving you testimony on two sides of an issue, what do you do when they disagree? If you've got some people saying that neutrinos don't have mass, and some saying they do have mass. You maybe don't know much about neutrinos at all, how do you…?
> S: Um, look at the background of the people, look at other factors, contributing factors to this whole debate/argument, like, I'm sure these people are not arguing in a vacuum. So, yeah. Look at a lot of other variables, not just the experts.
> I: What else? Other peoples' perspectives on the argument, maybe?
> S: Yeah, that would help. Look at what reason might this one expert be saying this, like, if he's a political advisor or something, what motives might he have, or if this is a professor at a college, and the college has a tradition of doing X, you know, what reason might this be?
> I: When I, uh, when I talk about stuff like this to people, one of the things that comes up often times is politics. People claim to be political experts, and the responses I get from…
> S: Well, political expert by definition has to be biased.
> I: Oh.
> S: In politics?
> I: Right.
> S: Almost.
> I: So, I mean, say you have political experts. How do you decide between two of them? I mean, if you say both are biased, right? [mmmhmm]
> S: Well, political experts, I never really cared, I mean, it's more one of those amusing things you just sit there and watch 'em go.

Again, this shows that beliefs about expertise can vary easily with contexts. I did not even have to bring up politics to introduce that alternative.

On the survey, he was a low splitter. In his words, “Since I’m not a scientist, I don’t know what they’d say. So I would just… I’d just assume to say what a scientist would say. Which, um… that’s why I circled and squared almost everything.” On the two questions he split on, coursework since the initial survey led him to change his squared answers. He said, “When I square, I think it’s the correct answer, and if I don’t know the correct answer, obviously I’ll square what I circle, cause I’m trying to get to the correct answer.” This is evidence that he believes there *is* just one correct answer, and though I do not have as lengthy a split quote from him, it is clear that splits bother him. Now, many students that said this indicated they were worried mostly because there can only be one answer on a test. However, that context is very much in play when studying how “multiplistic” our students are. Perhaps in another context, I would see different degrees of multiplicity.

Summary of interview data

In my data, all students treated the squared answers as genuine attempts to get the scientifically correct answer, and whether an individual subject was a frequent or infrequent splitter, she would believe that the circled and squared answers *could* be reconciled. I also have multiple clear pieces of data from my subjects indicating that they do not adopt two-answer stances with respect to physics problems. The strongest hint of multiplicity I found came from Sarah in response to whether splits are worrisome. She literally says at the end here that there can be “two different answers,” but this could mean that the answers are different ways of explaining the same thing. If that is not the meaning, Sarah is not saying that two "different answers" would have the same truth value or would both be equally correct. Clearly, toward the end, the idea of two answers is still somewhat bothersome to her.

The interview questions about splits often focused on subject matter students had not yet covered in class. For a few cases, the student had received some tutorial-based instruction between the multiple choice part of the survey and his interviews. In those cases, the student often nullified their split. Questioning revealed that those students had, indeed, refined their intuitive ideas to be consistent with the physics concepts. More important from my perspective, however, was the expectation most students expressed that they eventually *would* be able to achieve a similar reconciliation regarding topics they had not yet covered.

In summary, it became apparent to me that there are not "real" splits between something a student believes and the answers she thinks a scientist would give. Often, even without a prompt, students would gravitate toward expressing differences between things that seem intuitive to them and the answer they think a scientist would give. I saw an opportunity here to take the question in a different and epistemologically interesting direction. If instead of asking students to distinguish between *belief* and scientist answers, I asked for a distinction between *intuition* and scientist answers, I could gain insight into student views concerning the reconcilability of formal and informal knowledge. That was the inspiration of my next task.

A modified version of the FCI split task

Task and demographic information

My modified FCI task was exactly the same as before, except there was no initial pass through the FCI, and the circle instruction was changed to "Please **circle** the answer **that makes the most intuitive sense** to you." This was done to deemphasize how students behave on multiple choice instruments (the first pass) and to reemphasize my interest in their epistemological stances on reconciliation. I gave this survey to a group of second semester (PHYS 122) introductory physics students at the University of Maryland. A total of 153 students took the survey. Most (108) had taken an epistemologically-focused course featuring tutorials and modified Interactive Lecture Demonstrations (Sokoloff & Thornton 1997). The other 45 students came from a strictly lecture-based PHYS 121 class.

The table below shows how the two groups behaved quite differently on this survey. Averages out of thirty items are shown with standard deviations in parentheses:

1^{st} semester Background:	Reformed Course	Traditional Course
N	108	45
Circle score	17.9 (6.2)	11.4 (5.5)
Square score	19.0 (5.4)	11.0 (6.4)
Number of splits	4.6 (5.6)	6.1 (3.8)

Table 4-4: Scores and splits on modified FCI task for students beginning PHYS 122. Numbers in parenthesis are standard deviations. The reform class scored significantly better for both circles and squares ($p << 0.001$). The traditional course split a little more ($p = 0.06$); see below for discussion.

The most striking difference is in the score averages. The students from the reformed PHYS 121 course scored much higher in both the circle and square tasks (p <<

0.0001). Also, despite the fact that the spread in split numbers was large for both groups (notice especially that the reformed students had a standard deviation greater than the mean – a small number of high splitters skewed this distribution somewhat), I can say overall that those taking the traditional course split a little more ($p = 0.06$), but this may be simply because lower scorers tend to split more, just as I saw for the original task. We will see later (in the section on Newton's Third Law) an example where differences between the classes for specific splits are significant.

A quick round of interviews

I wanted to convince myself that the new task was more precisely worded and avoided ambiguities better. Therefore, I conducted validation interviews with seven volunteers. Most of them agreed to hour-long interviews where I asked them background questions and carefully went over splits on their FCI items. The background questions were the same four used in my original survey. The Belenky questions from that protocol were removed because they do not explicitly probe attitudes about reconciliation.

Results from those interviews did not cast doubt on the validity of the new split task as happened for the original split tasks. Intuition splits did tend to indicate genuine discrepancies between a student's common-sense ideas and the answer she thinks a scientist would give.

Focus on Newton's Third Law (N3)

The following way of looking at my data differs from the way most physics education researchers look at FCI scores, and the split task makes it possible. Most FCI research performs pre- and post-tests and compares the percentage gain for certain modes of instruction. I will go a little deeper and look at what is behind the "right answers" that students choose. For the new FCI split task, I am most interested in the splits that arise when the student gets the scientist's answer correct because those splits indicate a lack of reconciliation between the student's common-sense ideas and what she has (presumably) *successfully* learned in class. Ideally, we as instructors do not simply want the students to know what the correct scientific answers are. They must also see those scientific principles as reconcilable with their common sense.

I focused on the FCI's four questions on Newton's Third Law (numbers 4, 15, 16, and 28) because that is a conceptually important and epistemologically difficult topic in the first semester's material. I compare data for two different professors' courses. One professor is a physics education researcher who is experienced in using tutorials, interactive lecture demonstrations, and peer instruction techniques, and I will call him "Professor A." The other (called "Professor D") is an experienced lecturer, but he did not include any explicitly interactive activities in either lectures or discussion sections. For purposes of this discussion, Professor A's class will be called "reformed" and D's will be called "traditional."

As expected and anticipated by previous research, the "reformed" class performed better on the N3 questions, getting 86% of their scientist answers right versus 47% for the traditional students. Previous research, however, has not addressed the more subtle question: is there a conceptual and/or epistemological difference between the traditional students who got the N3 scientist answers correct and the reformed students who got them correct? Specifically, in the context of my modified split task, can one say that the students in the reformed class not only knew the material better, but reconciled it better? I looked at all responses on the N3 questions where the marked scientist answer was correct and then determined how many of those answers were split by the students. Among the traditional students, 40% of their correct N3 responses had splits. By contrast, the reform students split only 13% of the time on their correct N3 responses. It is true that overall, the traditional class split more, but the smaller discrepancy there does not account for the large difference in the split percentages on these correct N3 responses.

PER studies have shown that more interactive, tutorial-based instruction produces greater gains in FCI scores, but my split task FCI goes farther. Not only are the *scores* better, but even among the students who get correct answers, I now have evidence that students from the reformed class have reconciled the difficult N3 concept better than their traditional counterparts. Even when traditional instruction "works" for a student, it seems to work less effectively than the reformed instruction in the reconciliation sense. This result is quite important, and in the next section, I will expand upon it. My next section will show how the new split task can even determine differences between two classes with smaller differences in implementation.

Comparing four courses

I saw that for Professor A (an experienced PER researcher) and Professor D (who used no PER-based reforms), the FCI split task was able to tease apart a difference in how students who got Newton's Third Law questions correct were able to reconcile them. It turns out that one can also compare courses that do not differ so drastically in application of PER-based reforms. If Profs. A and D represent "black" and "white" sides of the reform spectrum, I would also like to examine some shades of gray. Two other Maryland professors were studied, and I will call them Professor Q and Professor R as they were in the previous chapter.

Professor Q was inexperienced with PER and had not taught the course in a number of years, but wanted to fully integrate it into his course. His students did tutorials during their discussion period, and he used Professor A's lecture demonstrations and slides throughout the course. The other, Professor R, is a distinguished university professor and had been teaching a number of introductory and advanced courses over the last few years. His students were given the same tutorials, but he did not include PER-style interactions or ILDs in his lectures, nor were the tutorial items explicitly tested on in his course. For this reason, attendance in his tutorial sections was far lower on the average (60-70% in his as opposed to about 80-90% in Professor Q's sections).

It is helpful to have a graphical representation of what happened for the N3 questions. All N3 responses (there should be four for each student) are lumped together as correct or incorrect by the scientist answer given. Professor Q's class had N = 76 for this survey (number of N3 responses = 302 since there were two blanks). Professor R had N = 69 (number of N3 responses = 276). Then, the correct responses are divided into "reconciled" and "unreconciled" based on whether there was an intuition split for that response. The three categories (incorrect, reconciled, and unreconciled) are depicted as percentages of the whole number of responses. Below are the data for professors Q and R as described in the previous section:

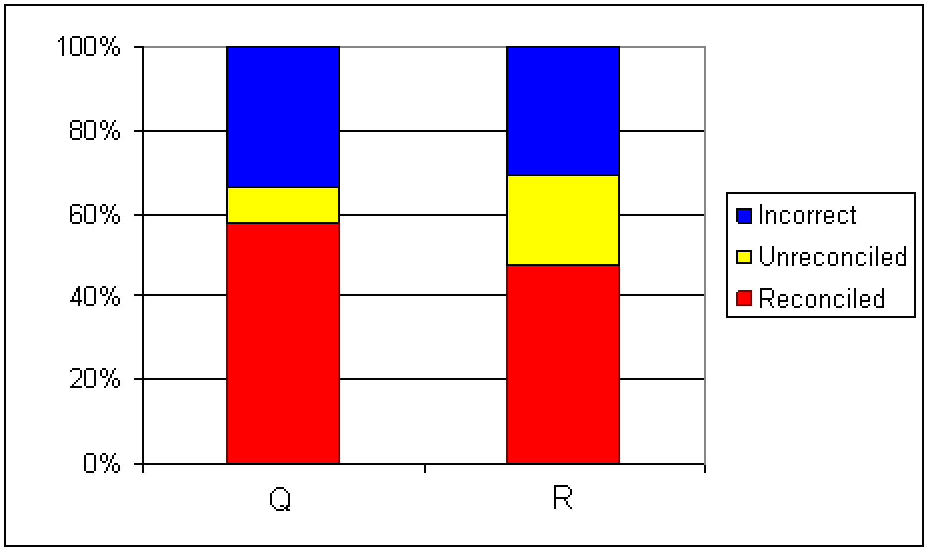

Figure 4-1: A comparison of Newton's Third Law responses from the post-test of PHYS 121 for Profs. Q and R. Q's class got significantly more correct and reconciled answers ($p < 0.001$) and had a higher percentage of correct N3 responses that were reconciled ($p = 0.0011$).

The middle section of each bar represents correct scientist answers with intuition splits. These constituted 8.6% of Professor Q's total and 21.7% of Professor R's. Compare that large difference to the overall correct scientist response rate of 67% for Q and 69% for R. Statistical t-tests show that neither professor's class gets significantly more of the N3 scientist answers right, but when one looks at the number of correct *and reconciled* answers on the N3 questions, Professor Q's class gets significantly more ($p < 0.001$). When comparing the percentage of correct N3 responses that were reconciled, Professor Q's class also beats R statistically ($p = 0.0011$).

Here is the implication: a standard FCI might not be able to distinguish the two courses very much with respect to performance on Newton's Third Law questions. However, the split task shows a subtle difference: Professor Q's students were more likely to refrain from splitting on their correct N3 responses. The MPEX2 from the last chapter was not able to fid a clear difference between those two professors' courses in this manner. The MPEX2 tries to paint epistemologically with three broad brushes (coherence, concepts, and independence), while the FCI split task is able to differentiate between these two "shades of gray" because the probe is more specific in considering reconciliation on N3 FCI items only.

When I bring all four professors in together, the results are much more dramatically different, as one can see in Figure 4-2 below. Professor A (entirely reformed) had N = 108, and Professor D (a traditional course) had N = 45. An analysis of variance comparing the four classes shows that the number of correct, reconciled N3 answers given depends significantly on the professor ($F = 35$, $p < 0.001$, $R^2 = 0.275$). Also, the percentage of correct N3 responses that were reconciled depends significantly on the professor ($F = 11$, $p < 0.001$, $R^2 = 0.112$). This result holds up even if one controls for the number of correct scientist answers; the percentage of N3 responses that were reconciled does depend on professor ($F = 9.6$, $p < 0.001$) but not on number of correct answers ($F = 0.065$, $p = 0.8$).

This leads to my most telling result: students in epistemologically-centered reformed classes both understand and reconcile the Newton's Third Law concept far better. The fraction of the respondents that get the scientist answer right and do not split that response from what makes intuitive sense is greater for the reformed class's students (versus the purely traditional class) by almost a three to one ratio.

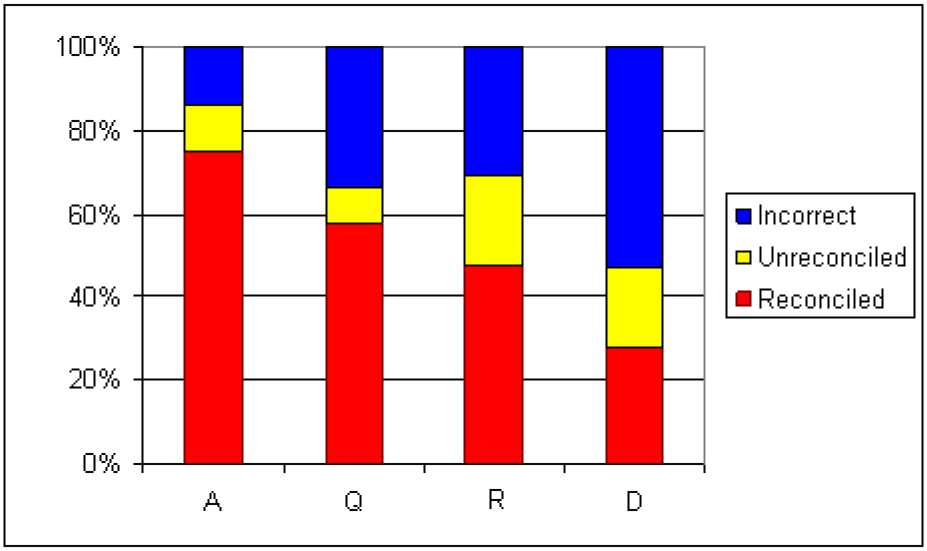

Figure 4-2: A comparison of Newton's Third Law responses from the post-test of PHYS 121 for four different professors. Both the number of correct and reconciled N3 responses and the percentage of correct N3 responses that were reconciled depends on the professor ($p < 0.001$), even when the number of correct answers is included in the ANOVA model.

Summary and further discussion

Split task summary

The question, "Do students really believe the answers they give on a standardized physics survey?" led me to come up with a modified version of the standard Force Concept Inventory (FCI) survey task. I first asked University of Maryland and Davidson College students to go through one pass of the survey as normal, and then presented them with a task where they had to square the answer they thought a scientist would give and circle the answer "they really believed." I found that women tended to split on FCI questions more on average and the spread in the amount people split for both genders was quite large. However, I had to control for FCI score since lower scorers tend to split more and women scored lower on average than men. Statistical analysis did not reveal conclusively whether there was a true gender effect.

The task for me then became to determine if a split really meant what I thought it did. Namely, do students see instances they split as cases where there is more than one correct answer? What could the students be meaning in their interpretation of an "answer a scientist would give"? One possibility I considered was that students could occasionally be labeled as *relativists* (or "multiplistic" in Perry's sense – see Chapter 2) who can see similar truth value in multiple choices or *absolutists* driven particularly by scientific authority. In my interviews, a common thread was concern from the students regarding splits. They seemed to know that there is only one possible correct answer for the FCI items. My subject "Sarah," who displayed the strongest relativistic tendencies, backed down from pure relativism when I probed deeply enough.

I felt finished with that line of the research. Since there were no score-independent gender differences on the original split task and I could not find explicit multiplicity about science in the interviews, I took the opportunity to change focus somewhat. Many interview subjects took my split task as a prompt to discuss whether an answer made intuitive sense to them. Since that came up often enough, I thought I could turn the FCI split task into something that explicitly studied reconciliation. Now, my research questions changed from wondering "do students really believe the answers they give on standardized instruments such as the FCI?" or whether there were gender splits or evidence of multiplicity, but "can one tell how well on average a course's students reconcile correct scientific answers with their intuition?"

The data gathered from the modified split task was interesting for several reasons. For one, it allowed me to distinguish between two professors (B and C above) who ran their courses just a bit differently. The difference is only visible in a very fine-grained context, that is, reconciliation with respect to Newton's Third Law questions on the FCI. Though both courses had students getting scientist answers correct with roughly equal frequency, the course (B) with closer ties to PER reforms had a higher percentage of students not splitting between intuition and those scientist answers. This gives evidence that on average, they reconciled better. The results were even more telling when the study was expanded to include two other professors: a PER expert and a highly capable professor not tied to PER. The classes on the "extremes" of PER implementation had approximately a factor of three difference between the percentage of their students to correctly (with reconciliation) get the N3 questions right. This dramatic result is caused by the explicitly epistemological nature of the N3 tutorials used in reformed physics classes at the University of Maryland, and all I needed to do to see it was restrict my observational scope appropriately.

Challenges to other current research methodologies

A common research paradigm in physics education research is to assess the effectiveness of various curricular reforms by using a standardized implement such as the FCI or FMCE. Both of those instruments are easy-to-administer surveys that cover essential conceptual material. Of course, this paradigm can and will validly continue long into the future. It is appropriate because some visible evidence of a gain in conceptual understanding is often considered an important instructional goal.

The most recent FCI split task provides an alternative. It simultaneously measures development along both conceptual and epistemological axes. It also helps raise the question: what *should* we consider the main goal of conceptual instruction? Would we rather cultivate a group of students that can get over 90% on the FCI but believe none of it meshes with their common sense, or would we prefer another hypothetical group who get fewer questions right but understand the correct answers they gave more deeply? If epistemological development (especially with regards to reconciliation) is an important goal for an instructor, we need a way to tease that apart from mere conceptual acceptance.

All of this discussion is at the surface of a pertinent question in physics education research: what should the goals of physics instruction be? What kind of balance is appropriate between fostering epistemological development, conceptual understanding, and mathematical formalism? While I will not resolve that issue in this dissertation, it bears noting that widely used assessments in PER are usually not tailored to an individual instructor's goals. Since the University of Maryland introductory classes I studied were taught or guided by professors with a particular desire to foster reconciliation along with conceptual understanding, the newest FCI split task was appropriate.

Similarities and differences with the MPEX2

Both the MPEX2 and FCI split tasks are meant to be used as evaluations of courses, not individual students. Though I interviewed individual students in developing these instruments, those were used for validation purposes only. Both surveys are multiple choice and easy to administer to large groups of students. The methodology is typically the same for research with both: change professors or instructional methods, and compare changes in the student population before and after instruction.

The functional features of the two instruments are quite different, however. The FCI split task is based on a conceptual survey with absolute answers. The epistemology was not explicitly there until I added it purposefully with the split instructions. Also, though it does measure a type of epistemological development, its scope is quite narrow. Attitudes about reconciling physics ideas with common sense are a very specific coherence issues. That sort of issue would be represented by at most one or two items on a survey like the MPEX2.

In summary, the FCI split task took a conceptual survey (and course evaluation) and turned it into a narrow epistemological course evaluation. The MPEX2 took a survey that combined some epistemological belief study in with expectations questions and tried to make the focus explicitly more epistemological. The explicitly epistemological items cover very broad categories of beliefs concerning physics knowledge (importance of conceptual understanding, coherence, and independence).

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Chapter 5: Small-N Case Studies Using Video and Interviews

Introduction

This chapter is an outgrowth of Hammer's thesis work (1994), and it serves as the best example of my research that follows Sandoval's (2005) program of study for personal epistemology. I do not strive to address all of Sandoval's research agenda, but we do touch on several aspects he finds important. Most importantly, my study is an examination of students' practical epistemological ideas. Specifically, I study relationships between one-on-one interviews and data (both videotaped and written) from classroom discourse and how that data sheds light on individual practical epistemologies. I do not study epistemologies as longitudinally (across grade levels) as Sandoval does, but I do allow for observational interplay across a semester course. My program outlined in this chapter avoids several critiques that Sandoval makes: I do not assume blanket coherence of students' epistemological beliefs and I do not rely on multiple-choice instruments except for comparison to more open-ended data.

I discussed Hammer's 1994 work in detail in Chapter 2. To summarize here, he sought to create a theoretical framework of students' epistemological views within the context of an introductory physics course. He interviewed students over the course of the semester using questions ranging from open-ended questions like "How is the course going?" to specific items about homework or tests the students have worked on. His framework developed three (not necessarily independent or orthogonal) axes that were centered on the role of coherence, concepts, and independence in physics learning. This framework inspired the MPEX surveys discussed in Chapter 3. My work here does not seek to duplicate or verify his framework, nor does it attempt to create a new framework. However, it is different in that it uses video of students to inspire customized interview questions. With these interviews and video together, I seek to tell rich epistemology-centered stories that could provide causal explanations for the physics learning difficulties the student I focus on has.

For this chapter, I will first outline my study methodology. I interviewed two students over the course of a semester, and I will write here in detail about one of them. I customized the interviews for each person and made them relate directly to a lesson they had just completed under the watch of a video camera. Upon looking at my data, I will make two key points. First, I will argue that the compound methodology using video and interview not only can give *richer* data that could not have been obtained with one of the methods, but can give qualitatively different results than just one data stream. Second, and more importantly, I will show details of one of my subject's personal epistemology within the context of their introductory physics course.

In the case of one of my subjects, I posit that her key epistemological stance is that reconciling concepts in physics with common sense simply involves manipulating the language until the right answers come out. Video and written data from this student would lead one to think her entire group conceptually understands the material, but further interviews demonstrate that "glossing over the language" is really all that is happening. Later, I show that there are real consequences for this student's learning. Because her epistemological stance toward reconciliation is not centered on understanding what aspects of common-sense thinking are correct and incorrect, her understanding of specific topics is less robust and does not transfer well to other situations that use the same principles. Lising and Elby (2005) note that causal expositions such as this are just now becoming more prevalent in the literature. Sandoval also suggests investigating these links.

The details presented here will demonstrate how epistemological issues can affect learning in physics class in ways independent from mathematical or conceptual competence. This demonstration lends credence to my methodology and supports it with a specific causal mechanism which supports claims from correlational studies that epistemology affects learning.

Methodology

Subjects

The setting for this study was an introductory algebra-based physics course at the University of Maryland, College Park (PHYS 121). Most of the students in the course are juniors and seniors, and a large number (about 60%) major in the life sciences. Unlike the engineering physics courses at my university, a majority of the class is female. It satisfies the physics requirement for Maryland's pre-med program. The students typically focus their first two years on major requirements, and so they will put off the physics course until later in their college careers. Many of the students have taken physics in high school, and most have taken one or two semesters of calculus.

The course in question is a PER-influenced course that has been discussed in previous chapters. Recitations used interactive, conceptual, and epistemologically-centered tutorial worksheets, and a course center was used where students worked on assignments in groups with minimal TA assistance. The worksheets (see a sample in Appendix E) focused not on the destruction of incorrect beliefs but rather on reconciliation of intuition with the physics being learned. They also contained items where the students had to reflect on the purpose of the learning activities. My interviews often focused on student responses on both the content of these reflective items and how important they felt the questions were for their learning.

I solicited volunteers for the interview study at the beginning of the class. Though I had served as a teaching assistant for the class in the past (thereby giving me familiarity with class proceedings), I was officially disconnected from the course. All students filled in consent forms for our tutorial-improving purposes. The same release was used for this project. Students were asked if they'd be willing to do a 30-60 minute interview about each tutorial after they had completed it. Also, they were told that no extra credit could be given for participating, since not everyone can participate in the study, but they would be paid regularly. Five volunteers originally signed up, and then all but two dropped out before the interviews began.

My two subjects will go by the pseudonyms "Patty" and "Sunil," and the subsequent analysis focuses on Patty. Both were third-year students (juniors) at Maryland. Also, both were cell biology majors, and they had both taken two semesters of calculus in college. Neither had taken physics in high school, and both chose the algebra-based PHYS 121 (over the calculus-based 141 – a course that fulfills the same requirements) because they were apprehensive about the higher math level required in PHYS 141.

Procedure for videos and interviews

All students in PHYS 121 have lecture for three hours a week, lab for two hours a week, and a discussion section in the hour before the lab. This discussion session provided all the video for the present study. The first interview consisted of a discussion about the FCI split task described in Chapter 4. Relevant FCI questions were fair game for a given week's tutorial. Each week after the introductory interview, my two subjects would go through the tutorial while being videotaped. I scheduled the interview as soon as possible after the tutorial/lab period. Patty's interviews happened immediately after the lab. Sunil's happened later in the week due to time constraints. In both cases, I conducted the interviews about a given tutorial before the next one happened, which I believe to be the essential timing requirement.

My qualitative data analysis was similar to that used by Seymour and Lehrer (2006) in their studies of teachers' pedagogical content knowledge. Observers (usually myself) noticed patterns in the video and interview data and tried to make general hypothesis along those lines. Seymour went on to use certain ideas as "tracers" when looking at data across many days of lessons. I did not employ a strict tracer concept, but there was a great deal of interplay between data collection and analysis. Analysis of one of my weeks affected the data collection (in the form of interview questions) for subsequent weeks.

For both students, I immediately removed the tutorial video once the class was finished and watched it to prepare for the interview. This was done without any strict procedure. I focused on Patty's epistemology and its relation to her learning. Explicitly epistemological questions were good focal points for the interview, but they were too small a part of the group discourse to be used exclusively. I always made sure to ask about the group responses to these epistemological questions, or lack thereof. If the tutorial group found the questions about reconciling and reflecting useless, I wanted to know about that, too. No explicit videos were shown to my subjects, nor were exact transcripts used to cue their recall, but I would loosely mention things that the student said or noticed during the tutorials. Appendix D contains the interview transcripts. Interviews were only semi-structured. If something came up in one of the responses that I wanted elaboration on, I asked right in that moment. Questions tying events of one week to events of previous weeks were also fair game.

I typed up the interview transcripts afterwards and read through them to look for interesting interactions. The main way the interviews and video work together is that the videos inspire appropriate interview questions, but evidence for epistemological artifacts can appear in either place.

Interview data and the modification of subsequent interviews and analysis

Data from Patty's video and written work

One tutorial that has historically provided the most compelling reconciliations and "a-ha" moments is our tutorial on Newton's Third Law. Due to a wealth of common experience, students have a hard time believing that objects of different sizes exert equal and opposite forces on each other when, in many situations, it clearly looks like the smaller object receives the bigger force. The reconciliation process takes up a good portion of the worksheet. Instead of focusing on forces, for one example, we have the students make predictions about a collision. Specifically, a moving car is hit from behind by a truck twice as massive, and the truck loses 5 m/s of speed. The students usually predict the car gains 10 m/s because it is half the weight and should respond twice as much. Then, they can carry out the calculations to show the forces on both objects are equal. Hopefully, they learn that by attending to velocity changes rather than what collisions look like, they can *start* with a "raw" intuition that can be refined toward correctness. Again, this shows a subtle difference between University of Washington tutorials and ours. Their tutorials include a "resolve" step, but ours explicitly try to make sure the raw intuition is neither ignored nor replaced.

These intuition refinements are reinforced in lecture demonstrations as well. Our interactive lecture demonstrations (ILDs) are written (like the tutorials) with an epistemological focus, and they are inspired by the work of Sokoloff and Thornton (1997). In them, we ask similar epistemological questions and occasionally (as in tutorials) use "Intuition Refinement Diagrams." These diagrams show a commonsense idea in physics, and then two alternative ways that intuition can be refined. One of the alternatives is the desired reconciliation. Following the Newton's Third Law tutorial, the instructor of Patty and Sunil's course gave an ILD on Newton's Third law where the following intuition refinement diagram is used:

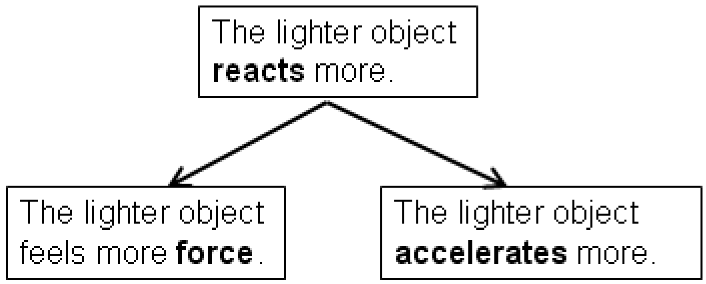

Figure 5-1: An intuition refinement diagram for Newton's Third Law

The top box represents the commonsense idea many students articulate when seeing a collision or "pushoff" between two differently-sized objects. The branch to the left represents a reconciliation path that leads to an incorrect answer, and we would like them to see that the branch to the right can be a way to reconcile.

When developing the interviews, one way I came up with questions was looking for interesting clips in the video. In the Newton's Third Law tutorial, Patty, unlike most students, did not predict that the smaller car would increase its speed by 10 m/s. Since this happens so rarely, I constructed interview questions about the episode. A transcript of the group's discussion (with no teaching assistant present) follows. Patty is S3.

> S2: So what'd we say about three?
> S3: I'd say it would, uh, gain five meters per second during the collision.
> S2: I said it would speed up ten because I was, like, "well, one's double the mass, so why not?"
> S3: We just *saw* the experiment.
> S2: But I was doing intuitively.
> S3: Oh.
> S4: I didn't really understand what they were asking in the first place. So, they're saying that, um... like, basically, when the car... when the truck hits the car, like, how... like...
> S3: When it hits the car, the truck slows down, and the car was still [OK] how much is the car gonna speed up?
> S4: OK. I would say 5 meters... 5 meters per second.
> (pause)
> S3: OK, apply the intuition that the car reacts more. I mean, you could think it's reacting more because it's speeding up, so that seems like more reaction than something slowing down, even if the rates are equal.

Patty came up with an interesting justification for how her prediction agrees with the instruction to "apply the intuition that the car reacts more." Most students either agree or sympathize with a 10 m/s speed increase. Even if the group ended up working everything out, I wanted to figure out where this answer came from. Also, I wanted to see how robust this thinking or any new thinking was going to be.

Later on, after a few more minutes of work, Patty's group completed the last few problems and called the teaching assistant (TA) over to check their work. A snippet of the video transcript follows. Patty is still labeled as Student 3 (S3).

> TA: So, at the beginning of the tutorial, you guys had this intuition about, well, a lighter object is gonna react more in a collision. Right? And... and in a... you went through, did some calculations based on that, and it came out and it agreed with Newton's third law, right? But at the very beginning... uh... very beginning of the tutorial, you guys said it disagreed, right? So... how do you reconcile that?
> S1: I think we were thinking before, when we were talking at this checkpoint, that it really depended on what we were looking at [OK], cause in the beginning, we were talking about the acceleration of the car, and our calculations helped us figure out the force [OK], so it really depends on what you're looking at.
> TA: So, if I understand what you're saying, what you're saying is that your intuition was really telling you about acceleration, but then... you thought it was telling you about force?
> S1: Yes, in the beginning. And then, I guess [OK] the tutorial guided us through the...
> TA: OK, so... so now you... now you say it has to do with your acceleration, and so... does this mean that you can trust your intuition?
> S3: Sure.
> TA: Hm?
> S3: You just gotta know what it's talking about.

One reason I would want to interview a group like this is that if I am doing a case study on Patty specifically, her terse responses in this clip would not tell us much.

One might get more information from Patty's written work. On one tutorial question, the group is asked, "what's up with the *car-reacts-more* intuition? Is it wrong? Is it right? Is it something else? Explain." Patty's written response was "our intuition was about acceleration, not force." To conclude, the tutorial asks what it calls the "most important question in the tutorial": "What general strategies are suggested by this tutorial – strategies you might be able to use with counterintuitive concepts appearing later in the course?" Patty's response was, "our intuitions are not always wrong but sometimes just about something else." While she didn't really take the question about strategies seriously, her answer does not look bad at all to someone interested in her group's reconciliation of the physics concepts with common sense. Between her group's responses on video and Patty's written work, one might conclude that she got the conceptual (and possibly the epistemological) point of the tutorial. One could even read these responses alongside the intuition refinement diagram and argue that her group met their objectives. More discussion along these lines will follow the data.

Data from Patty's interviews

When it comes to explicitly epistemological questions, tutorial groups (especially in the beginning) tend to gloss over the questions. A sample question from the Newton's Third Law tutorial reads:

> A. "In summary, for most people, Newton's third law contradicts the common-sense intuition that the car reacts more during the collision. Which one of the following best expresses your attitude toward this contradiction?
>
> i.) We shouldn't dwell on these kinds of contradictions and should instead focus on learning exactly when Newton's third law does and doesn't apply.
> ii.) There's probably some way to reconcile common sense with Newton's third law, though I don't see how.
> iii.) Although physics usually can be reconciled with common sense, here the contradiction between physics and common sense is so blatant that we have to accept it.

Patty's written response circled the first and second choices, and for an explanation, she wrote, "There's probably a way to reconcile but we shouldn't waste time trying to figure it out and should just focus on learning when the law does and doesn't apply."

This response is not necessarily counterproductive with respect to succeeding in coursework.

I pursued this question in our interview. Student 2 was a male student in Patty's group.

> I: Or something like that. Um... you and [Student 2] both said you were kind of torn between one and two. Now, he sort of made a comment about why one was appealing, but you didn't say too much about it. Um, [well, I...] do you know why you were torn between choices one and two on...?
> S: The same reason as him. Like, I like the first part of one, we shouldn't dwell on these things, and stuff.
> I: OK, uh, and... why do you agree with that? What about that part of choice one is appealing?
> S: Well, you're not gonna really learn anything by just sitting there dwelling on it, and, like, worrying about it, I mean... I don't know. So, like, that part of choice 2 saying there's probably some way to do it, but right now I don't know. And part of choice 1 saying I shouldn't dwell on it, and we should focus on learning. I like that, too.

This data meshes with my later analysis. There, I will show other evidence that Patty does not value dwelling on conceptual contradictions. This view is certainly not unique to her, but it will take a little more effort to see what thinking mechanism is at work in her case.

We moved on. I was curious about her attentiveness to her prediction that the car would gain the same amount of speed as a larger truck would lose in a collision.

> I: OK, so... can you articulate for me... [well] how... I mean, you said... I know you said something about it on the tape, and I have it down, but I just wanted to see what you said... what you say now... how the 5 relates to a "car reacts more" kind of idea.
> S: Well, I was just trying to come up with something how intuition would not interfere with what the law stated, and the law said that things must be equal.
> I: Uh huh.
> S: And we didn't know at this point whether we were talking about force or acceleration, we hadn't gotten to that part yet.
> I: Right.
> S: So the law says it's equal, and intuition says it's different, so... [mmmhmm] going by the law, it's gonna have to be 5. But, like, if you just think about it, like... when something is speeding up, you tend to think, like, more force, more power needs to go into something that's speeding up than slowing down.
> I: Can you think of a specific physical instance where it's harder to speed something up than it is to slow something down by the same amount?
> S: Well, um, if you're pushing something, it's a lot of force to, you know, push it, but if you need to slow something down, like, there's other forces involved there which help you, so it's not as hard to slow something down as it is to speed it up.

I: What might help you?
S: Friction, gravity...

It seems that Patty was desperate enough for *something* to be equal between these two objects that she stuck with the “5 m/s” prediction. In the moment, I got the sense that Patty did not have the ideas about needing more force to speed something up ahead of time. It is possible she could have been developing these ideas on the spot. Later in the transcript, she confirmed that her prediction was tentative by saying, “Wait, I wasn’t, like, steadfast as… this is the way it has to be, but I just threw out another idea of how it could possibly work.” Another piece of evidence supporting the spontaneous generation of the 5 m/s answer came from the first bit of video transcript above. She justifies her answer by saying to Student 2, “We just *saw* the experiment.” To her mind in the moment, the experiment somehow justified the answer she gave. Although I will not be able to make blanket generalizations about physics students in general from this data, I can learn rich and interesting things about the few individuals I do study. The next section of this chapter will hammer home this main point. For Patty, I will find that her difficulty in reconciling lies in her tendency to see learning not as a thought-refinement process but as a game involving the use of language. Learning for her is a game of figuring out which words to use, therefore, no true reconciliation is necessary.

A deeper look at issues in personal epistemology: Patty

Further interview data from the Newton’s Third Law tutorial

Looking at the rest of Patty’s interview transcript from the Newton’s Third Law tutorial reveals insight into the strength of her reconciliation as well as a significant epistemological issue. Many of my interview questions are of the form "what was the point of…," referring to various parts of the tutorial. In the N3 tutorial, the first question refers to a truck hitting a parked car. It asks, "According to *common sense*, which force (if either) is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck. Explain the intuitive reasoning." Naturally, we expect the students to say the force from the truck is larger. This could intuitively be because the truck itself is larger, it is moving, or because they know the car will get smashed. My interview snippet about this part of the tutorial went like this:

> I: What do you think the point was, or do you think there was a point in... in talking about it at the very beginning where you had to say something that was wrong? Right? That... that it seems the forces weren't equal.
> S: Well, um, kind of tricky, because they don't really tell you exactly what... I mean, just... what's greater, or which force is greater. And without knowing exactly what force is, cause we're pretty well just started, we just thought up acceleration and thought that was the force, so...
> I: Oh, so... so for you, part of the confusion was not really understanding what force was.
> S: Well, I guess so.
> I: OK, so was... was the point of this to... to clarify that concept, or something else?
> S: The point of the beginning, you mean?
> I: Yeah, the first section, making you... I mean, not forcing you, but giving you a question that, you know, we know a lot of people screw up.
> S: Well, it makes you aware of what you commonly think of as force was actually acceleration.

From the quotes "without knowing exactly what force is," "we just thought up acceleration and thought that was the force," and "what you commonly think of as force was actually acceleration," one can see a potential word issue here. If the group was simply using the wrong term to describe their intuition, there is really nothing to reconcile in their mind. Now, based on this exchange alone, an instructor could be convinced that Patty really understands the issue, but several possibilities exist. She could be properly recognizing that her group attended to acceleration initially.

Alternatively, she may be glossing over the language, which would not be the ideal reconciliation strategy. I would need more data to tell what is going on.

Since Patty had not elaborated well on strategies for dealing with conflicts between physics and intuition, I asked her about that:

> I: So you're gonna... you're gonna be forced to deal with stuff like this all the time, so... what can you do to deal with it?
> S: Well, if it doesn't seem to be making sense intuitively, we can think about exactly what our intuitions are talking about... if we are actually thinking of the same terminology as we are experimenting with, and make sure our mathematics are right.

She may have been able to think this way to "get" what the tutorial was trying to do, but this is an explicit and personal epistemological issue. Part of a students' epistemology deals with how he or she believes apparent contradictions with common sense are resolved, and Patty seems to think here that getting the terminology right is the important thing. The problem with applying epistemological resources in that way is that the final reconciliation may end up tenuous.

Evidence of tenuous reconciliation from the FCI split task

Patty's group seemed to reconcile Newton's Third Law with their intuitions in the video and written work. To see how robust this reconciliation was with Patty after the tutorial, I asked her one of the N3 questions on the Force Concept Inventory. I included the part about which answer makes the most intuitive sense. All three N3 questions on the FCI require stating that two objects exert equal and opposite forces on each other. If the tutorial achieved its epistemological aims, Patty should either see that the correct answer makes the most intuitive sense or believe that the correct answer is potentially understandable in intuitive terms. The following snippet of interview occurred after the tutorial discussion was complete:

I: So, a truck colliding head-on with a car... (pause) I think I asked you about this the first... the first time I talked to you.
S: Yeah, probably.
I: So, which of those makes the most sense now?
S: Well, it's E. They do an equal and opposite force.
I: OK. And, I mean...
S: If you're defining force in terms of what we used in the last tutorial.
I: H... how does that work? I mean, with... how do the forces end up being the same in this particular collision? I mean, the car clearly gets smashed.
S: Oh, it gets smashed?
I: Yeah, I mean, the small compact car... it's a head-on collision, so [oh], what happens when the car and the truck collide?
S: Oh, so they're both moving?
I: Yeah.
S: Hm. Well, I don't know, we didn't talk... I was actually thinking at one point, I was gonna ask the TA of that, and then I forgot [uh huh] what happens if the car just gets obliterated by the truck instead of is accelerating. But, um... probably still be E.
I: Um, OK. (pause) So, so the car clearly gets more damaged in the collision.
S: Mmmhmm.
I: So...
S: I suppose force can connect...
I: How is it that it makes sense to you that the forces are the same for this case?
S: Well, I suppose the force can manifest itself in things besides acceleration, which is... what we dealt with specifically was acceleration, but I'm sure there's other things it could. it could come out as. Be observed as.
I: Like what?
S: Well, heat, probably.

At the beginning of the interview clip, she gives that E is correct. She clearly knows this is the correct answer. I followed up by asking how it makes intuitive sense that a truck smashing a car could involve forces of equal magnitude. Patty's remark that "the force can manifest itself in things besides acceleration" is not something that a person who really got the reconciliation point of the tutorial would say. She is being sophisticated in "sensing" that this situation feels different than the one discussed in tutorial (it would have been interesting if she actually asked the TA about this case), but the answer she is seeking does not seem to be a true reconciliation. Could it be another "glossing-over" using language?

A different FCI N3 context comes in the problem where two students are on rolling chairs and the larger student pushes off the other student with his legs. Patty knew the correct answer, and I pressed for elaboration in the interview:

> I: So, what about that tells you that the forces are the same, or helps you make sense that the forces are the same on the two people?
> S: Well, they're the same cause they're touching, and... I... I don't know, I hadn't considered direction in affecting the force that much. I mean, if they're pushing away or... going in the same direction they're pushing, they're still exerting force on each other.
> (pause)
> I: OK, so... I believe... I understand that, you know... you know they're exerting forces on each other.
> S: Mmmhmm.
> I: The question is... what about the situation helps you make sense of the answer you gave me which said that the forces are the same size? I mean, how can I look at this and sort of intuitively think, "OK, those... those forces are about the same"?
> S: Well, well I don't know. But, uh... if they're about or exactly, that... according to Newton's Law they have to be exactly, cause that's just the way the world works. And...
> I: OK, so if... so... what would you say to me if I was someone in your group, right... and I said, you know, A is the one doing the pushing. You know, A pushes on B, and we see B flying off to the right.
> S: Mmmhmm.
> I: So... how can they be the same?
> S: Well, you're talking about something different than the force that Newton was referring to.
> I: Which force... was he referring to?
> S: I don't know... we need another term for force, because... yes. Student B is not doing anything, he's not exerting himself physically in any way, he's just sitting there. And B... or A is doing work, he's... um, you know, his muscles are moving, and he has to pump the blood, and all that, so he's actually doing something. And that something he's doing... um, can be called force, but it's a different force than the type of force where... two objects are touching, so they have to be exerting the same force.
> (pause)
> I: Oh, so... hm... so this isn't the case like the car and truck collisions, so...
> S: Sure it is!
> I: Oh, wait, it is. I forgot what you were responding to exactly. Um...
> S: I mean, I haven't seen anything to tell me that this is going to be any different from any of the examples we've done where the forces are always going to be equal and opposite when things are touching.
> I: There's something about the term "force" you don't like?
> S: Yes. It's too broad.

Again, Patty expresses the feeling that “you’re talking about something different than the force Newton was referring to” and the term “force” is too broad. Despite the fact she knew the correct Newtonian answer, she resorts to saying that she has no evidence this problem will be different from the others. The way she sees the word “force” as slippery leads to mere acceptance here, not real reconciliation.

Another N3 example question from the split task might tell us something. The N3 item involves a car pushing a truck, and the car is accelerating. Here was our dialogue on the subject:

> I: Uh, what... that A is the correct answer?
> S: Yes.
> I: Does that make sense in this... in this case?
> S: Sure.
> I: How?
> S: Well, they're touching, so there'll be force, and it's gonna have to be equal and opposite.
> I: OK. So... I mean, it... it sounds that you... that you've accepted that Newton 3 holds in this situation.
> S: Yes, I have been.
> I: Uh huh.
> S: Accepted that.
> I: The car's doing all the pushing. So if the... if the truck resists the car as much as the car pushes the truck, then how can it accelerate?
> S: Well, you just used the term "resist" and...
> I: Exerts. Oh. Good catch.
> S: And that's the same thing as the type of force we're dealing with, I don't think so. I mean, it's... it's still touching the car, so it's gotta be exerting some kind of force.
> I: The truck is exerting some kind of force?
> S: Mmmhmm.
> I: Right, um... but, but I'm saying I might have the intuition that [OK] that force can't be equal, cause if they are, how can I speed up if the truck pushes on me as hard as I push on it? Me being in the car, of course.
> S: Right.
> I: Mmmhmm.
> S: Well, that's right, and I think that's what I put when I first read it, but if... I mean, taking the wall into account, it has to, because they're touching. And the... when you say that you wouldn't be moving if you are exerting equal force, you're talking about something other than the force which Newton's law is talking about.

Her answer about how N3 is correct here seems based on acceptance. The last sentence might be the most telling. She seems to think people can make incorrect statements about physics because their use of the terms is incorrect. To her, there is a distinction between an intuitive sense of force (which would give her the idea that the car has to push harder for the truck to move) and the “force which Newton’s law is talking about.” This ontological stance can certainly affect the way she reconciles, and it would be helpful if I could see this in other tutorials.

Advantages and disadvantages of the combined approach

A combined and triangulated approach where videos, written work, and interviews are used together to study personal epistemology has provided many advantages. While interviews on epistemology can yield a lot of rich data with open-ended questions, my specific questioning allowed me to get at specific details of interest. If one compares her video and written snippets with the intuition refinement diagram in Figure 5-1, he or she would likely conclude that Patty's group traveled the correct fork and reconciled completely with no remaining loose ends. Patty's later interview quotes taught me a lot about the tentativeness of her answers and her hesitance to accept the epistemological message I thought her group had received.

The video data and written work presented already can serve as small examples of data that can prime a good epistemological interview and serve as a basis for follow-up questions in future interviews. In this case, this initial snippet is the particular example that inspired my look at Patty along an epistemological axis, namely, views about reconciliation. Without watching the progression of events, I would not have been able to ask specific questions about how the tutorial went. Also, since our tutorials attempt to get students to be reflective about their personal epistemologies, responses to those items are a good basis for interview items. In a group situation, students may feel pressured to "get on with it" and complete the worksheets as quickly as possible.

Naturally, this approach will come with disadvantages. Students always have the power in interviews to construct answers on the spot that may or may not have been part of their previous thinking. It is also logistically difficult to study people in this way, as evidenced by my low acceptance and high attrition rates for the subjects. Finally, one cannot really make general statements about student epistemologies from these case studies alone.

Evidence of similar behavior in other tutorials

At this point, I have found a possible epistemological pattern in Patty's reasoning: she sees reconciliation as something one does by correctly using and manipulating the language. In the Newton's Third Law tutorial, I have evidence that Patty's stance as a causal negative effect on the robustness of her reconciliation. What I would like to do now is look for confirmatory or contradictory evidence in later tutorials. I will point out other instances where her interview responses follow a similar pattern.

The tutorial after the Newton's Third Law tutorial covers Newton's Second Law. Like the N3 tutorial, our N2 tutorial features reconciliation between (sometimes) incorrect common sense and correct physics. It also uses an intuition refinement diagram. The central tutorial question deals with a small child (Timmy) that has fallen down a well. A machine reels in a rope to pull him up. The child weighs 250 Newtons, and is pulled up at constant speed. The question to be discussed: does the rope exert a force greater than, less than, or equal to 250 Newtons? Intuitively, many students say that the upward force from the rope (or machine) needs to beat gravity. The refinement diagram our tutorial has them use looks like this:

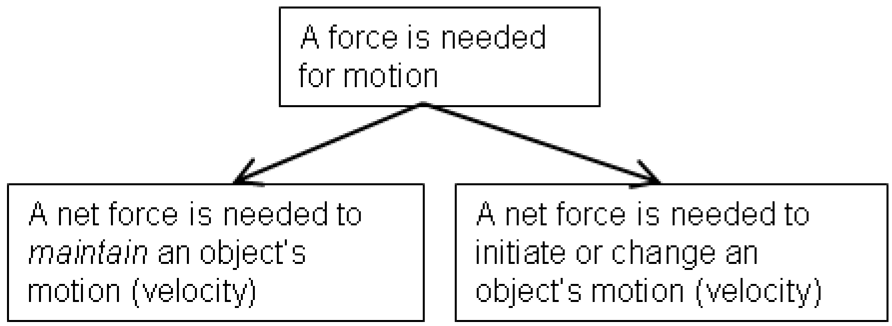

Figure 5-2. Intuition refinement diagram for Newton's Second Law

If a student understands at the end of tutorial that they were initially thinking along the left path, but that can be reconciled to thinking along the right path, we consider that good reconciliation. We try to get them to refine their initial intuition by supplying two other cases: one at the start of the motion where the child speeds up from rest, and one toward the end where he is ready to stop. Studying these cases allows the "constant speed" portion to act as an intermediate case.

Patty's work on this tutorial was very typical of our introductory students. She initially answered that some agent much be exerting a force greater than the child's weight, but also realizes that Newton's Second Law indicates an equal force. The rest of her responses, though terse, go along with the tutorial just as an instructor would want. She acknowledges that her initial intuition worked along the incorrect branch of the intuition refinement diagram, and that Newton's law employs thinking along the other branch.

One very telling reconciliation point I noticed from her written work was a question on the first page. She wrote that the boy is being pulled upward, so intuitively, the "rope force" has to be greater than his weight. Also, she knows that the acceleration is zero, and uses the term "equal forces" in that item. The tutorial asks the question, “Are you 100% comfortable with your understanding of this scenario, or is there still something that needs to be reconciled?” Her response was “Only 75% comfortable because Timmy is moving up.” Although I have written evidence from later in the tutorial that *some* reconciliation happened, the fact that she didn’t see a blatant contradiction between her initial intuition and Newton’s Second Law reveals an epistemological blind spot.

Moving on to the interview data, I see some instances dealing with language or reconciliation. Initially, Patty had a problem answering questions about the rope force because she believed the machine was acting as the true agency. She seems to believe that difficulty is overcome.

> S: I don't know, I just... the rope's not doing anything, the machine's the one exerting the force. It... I guess it really doesn't make that much of a difference.
> I: Why doesn't it make a difference?
>
> S: Well, just kind of... they were gonna be doing the same thing, and they're basically part of the same thing, so it really doesn't matter what word you use for it, whether you use rope or machine.
> I: For the thing that's exerting the force up?
> S: Yeah.
> I: OK. So, I mean, do you think you could... I mean, clearly you did, but, I mean, would it not affect the rest of the tutorial, then? If I replaced the word "rope" in here with the word "machine" every time it came up, I mean, would that... that not affect your answers or the way you thought about it?
>
> S: No, not after the first question where I was just kind of like, "oh, they're the same thing."

One of her groupmates pointed out a valid reconciliation statement in the very beginning: a greater force is needed to get Timmy going. I discussed that question with Patty.

> I: Your Newton... the Newton's second law answer, what does it say about the upward force, uh, during the part where it's... uh, where it's going up at constant speed?
> S: Well, it said it... that they would have to be the same force.
> I: OK. Um... you got that answer very quickly at the beginning. Did that contradict an intuition you had, or did it not?
> S: Well, it kinda does. Because, you figure, same force, it will not gonna be moving at all. But then... [groupmate] mentioned something which was actually what the whole second page was about, that, you know, once you start it moving, then it's fine.
> I: Then it's fine. OK. So, that... that's what I was going to ask about next. He, at the very

beginning, said that, you know, the kicker in this is that we have not yet asked you to consider the beginning of the motion where it goes from rest to whatever constant speed.
S: Right.
I: Um... I'm... I'm just wondering, since it wasn't immediately obvious for a couple of reasons, I was wondering when... when exactly that sunk in. Um... I mean, did you believe it as soon as he said it?

S: Yeah.

I: OK.

S: I just hadn't thought about it before, but as soon as he said it, it made sense, so I accepted it.

I am not sure if this reconciliation was robust despite Patty's assertion that she understood everything. I needed to look for other evidence later in the interview.

Later, I asked her about the intuition refinement diagram, since she did not say much about it on the videotape.

I: What kind of small things were giving you trouble?
S: Um, like, in part C, I don't know, I kind of wavered back and forth between answers there. When they wanted us to pick which one of these...
I: Oh, this is the intuition refinement diagram. OK. I... your group did get some responses about this, but you personally didn't say a lot of them, so I guess I'm wondering what you thought. Um... what... what was the problem here? You were trying to pick which of these refined intuitions applied to different parts earlier in the tutorial?
S: Yeah.
I: So what was the problem?

S: I just didn't know exactly what they were asking. Because the first one said part B. (pause) Um...
I: Above... I think this is formatted in the same way yours was.
S: Yeah.
I: So that one was referring to this part?
S: Mmmhmm. So... which way was I thinking? OK, for that one... (long pause) I guess that one could be either answer, depending on which way we were thinking.

I: Uh, what do you mean, you mean the definition of what net force is?
S: No, the answer to number one [uh huh] could be either... either one of these intuitions, because it depends on what your personal one was.
I: Well, right, so... so for part B, what was your personal one?
S: Um, I think it was this one, that needs to be... to initiate or change it.
I: And this is about the initiation phase of the motion, and you need a net force for that, right?
S: Mmmhmm.
I: OK. Um... and, and which one of them did you think agrees with Newton 2 more?
S: Um... (pause) I don't know. I thought it was the one to maintain, but everyone else thought it was the one to initiate.
I: OK. Were... were they convincing to you, or do you still believe that... that this one... this one agrees with N2?

S: I guess I don't really see much of a difference between the two of them, maybe. Like, OK, all N2 says is the force equals the mass times acceleration [uh huh], so... I don't know, you'd have to... I could see that fitting with either of those intuitions.

Admittedly, I first saw this as a case where she was not really using the intuition refinement diagram in the intended way. I was unclear what she meant by “I could see that fitting with either of those intuitions.” I pressed on, and asked what difference the word “nonzero” would make if put in front of “net force” in the refined intuitions. She indicated that the new wording made sense, and identified the correct refined intuition (a *nonzero* net force is needed to initiate or change an object’s motion). Still, I wanted to know her take on the reconciliation aspects of the tutorial.

Many of my interview questions take the form “what do you think was the purpose of ________,” where the blank is filled with some (usually epistemological) part of the tutorial. These echo tutorial questions where we ask the same thing. Regarding the issue of the rope force, one of the last questions in the Newton’s Second Law tutorial asks “Given that you’d already figured out the answer to this question in part I, what was the point, if any, of part II of this tutorial?” As a reminder, part II consists of the beginning and end accelerations. Seeing those should help one understand why net force is zero for a zero acceleration case.

> I: The acceleration is zero, so the net force is zero, so up and down have to be the same. Um... you never answered this, so what... I mean, what do you think one of your professors would say was the point of doing the other two? I mean, if you... you already got the right answer by the end of the first page, so...
> S: Well... um, we would have to understand that it would need to be greater initially, and then equal. That, like, just... when it was greater, we'd have a... a, you know, positive acceleration, and when it would less, then we'd have a negative acceleration. You don't really get that relationship by just doing the first page.
> I: Oh, I mean, it's just applying Newton 2 again, but we didn't ask you about the specific situations of starting and slowing down that were important. Is it just leaving that out?
> S: Well, yeah. The first page didn't talk about starting and stopping, it just talked about what happened in the middle.
> I: Oh, OK, so... so the second page and the third page talk about other stages that are important for getting it.
> S: Cause you don't move in this world without first starting and stopping.

While I can make an argument that Patty superficially got the conceptual point of the tutorial, she did not see our efforts as being geared toward reconciliation. Sure, she claims that our intuition-development pages are worthwhile as enumerations of different possibilities, but that is all. She had this to say about the structure of the tutorial:

> S: I didn't really get much out of part C.
> I: Why not?
> S: I don't know, it just... I mean... it was... it just, like, reworded it and asked kind of the same thing, it seemed.
> I: Reworded what?
> S: Well, parts of part B. I mean, we'd already pretty well answered what the net force is needed to do [uh huh], and this was just kind of a rewording of that.
> I: So, by here, you had seen all of the physical situations that are relevant [yeah], and, and though about how N2 applies, and gotten the right answer, and understood it, and by this point you didn't need to do anything else?
> S: No, I don't think so. I got the most out of this from part B. Part A was, like, a good intro to it, and part B, I learned the most. Parts C and D, was... I didn't really learn anything.

Part B, as she refers to it, is the list of cases: starting the motion, constant speed, and deceleration. Parts C and D contain the intuition refinement diagram and the reflection questions asking what the point of part B is if Newton's Law gives you the answer for the constant-speed case directly. Even though there is evidence Patty reconciled this concept with intuition to some degree, she did not see the intuition-refinement diagram or reflection activities as useful learning.

Unfortunately, I could not continue my pattern of asking a related-but-different FCI question, since the only FCI question that deals with this N2 issue explicitly is too similar (Find the upward force on an elevator moving up at constant speed). For both that item and a similar horizontal problem, she mentions that the answer where you must beat gravity (or friction in the horizontal case) is intuitively appealing, but she came to realize that this intuition applies to the initiation phase of both problems. This is correct and basically what we want students to get out of this tutorial. From this tutorial, I do not get as much evidence of glossing over language, but Patty's aptitude and attitude toward reconciliation (she can do it, but does not see it always as worthwhile or as part of “real learning”) is consistent across both the N3 and N2 tutorial contexts.

A case several weeks later provided a case where language issues made it difficult for me to gauge her progress with the conceptual topics of work and energy. In our work tutorial, we present a situation where a student pushes on a wall until she breaks a sweat. The wall does not move. Patty originally answers that intuitively, the student does work. Also, initially, she says the student does work in the physics sense. I lack data from that interview to tell whether any true reconciliation happened, but once again, she made a reference to language in our interview. The phrase “it depends on your definition of the word ‘useful’” appears, once again indicating that getting meaning right is more important than purely thinking about the concepts. I do not mean to sound judgmental here; often it is productive and correct for a physics student to clarify the definitions of terms. However, in Patty’s case, many aspects of thinking take a back seat to this task. Though the effects of this epistemological stance are sometimes small, they were particularly noticeable in our Newton’s Third Law tutorial.

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Chapter 6: Conclusions and Summary

Summary of results

In the first chapter, I indicated that this study addresses the following research questions: (1) What factors can affect how and whether a class succeeds at fostering epistemological change? (2) How can the combination of classroom video and interviews give us fine-grained information about a student's epistemology as opposed to broad characterizations? (3) Can a survey aimed at the specific issue of reconciliation see epistemological differences that a broader instrument misses? (4) What can triangulating interviews and video do for studying epistemology that one method alone cannot?

The literature review in Chapter 2 discussed where this work fits within currently held ontological and methodological frameworks in the literature. The simplest challenges to established methods came in my chapter on the modified Force Concept Inventory. Inspired by questions from Chinn & Samarapungavan (2001) and Mazur (1997), I wondered whether it was a problem if a student could get simple conceptual mechanics questions right but not really believe the answers. My chapter on the new version of MPEX discusses how that survey of intermixed epistemology and expectations can be focused better on epistemological issues and toward an introductory premed sequence course. The deeper challenges, however, came with my case study interviews (Chapter 5) and the methodology behind analyzing the MPEX2.

Many important works in the research literature posit a unitary ontology of epistemological beliefs. That is, they will either explicitly state a stage theory of epistemological development or tacitly assume a unitary ontology in their data analysis with factor analysis or something similar. Following the theoretical lead of diSessa (1993) and Hammer, et al. (2002), my work has largely followed a resources perspective that manifests itself in several ways. For one, I did not use factor analysis on the MPEX2 in order to verify epistemological coherences within students; rather, I preconstructed clusters that were used crudely to monitor the epistemological progress of an entire class. More importantly, though, I stayed loyal to the idea from the resources perspective that both conceptual and epistemological evaluation of students is flexible and extremely context dependent. My interview questions for the small-N case studies were tailored to individual students and specific situations.

I will address the other research questions with respect to the different methods pursued here.

MPEX2

Both the original MPEX (Redish, et al. 1998) and my new version of the survey indicate that they are not appropriate for analysis of individual students. Validation interviews given after a standard paper-and-pencil version of the MPEX show that the test-retest reliability for an individual student is questionable. However, those same interviews effectively showed me which questions needed modification either to remove false favorable or unfavorable scorings. I can get interesting results when studying the epistemological development of a whole class. While I found that achieving gains in the coherence, concepts, and independence clusters for an introductory mechanics course was difficult even in PER-influenced courses, I could get the gains if epistemological development was incorporated as an instructional goal. Even more interestingly, I found that two PER-influenced professors could get different effects (one with further gains, one with slight losses) depending on the inclusion of epistemologically challenging material like modern physics. The disconnect between the coherent body of previous material the professors tried to get across and the new, strange material in modern physics caused a drop in the class's MPEX score in the second semester.

Advantages of the MPEX2 compared to the other studies in this dissertation include a broad focus across multiple epistemological issues (as opposed to just one in the split tasks) and the ease of administering the survey to multiple students.

FCI split tasks

Unlike the MPEX2, which covers many epistemological domains, my final version of the FCI split task only deals with one aspect of epistemology and epistemological development: the reconciliation of conceptual physics topics with intuition. My work focused on how much students in courses "split" their answers, that is, how often they differentiate between the answer they think is scientifically correct and the answer that makes the most intuitive sense to them.

My most dramatic result from this chapter was comparing an epistemologically-reformed class with a traditional class with respect to student understanding and reconciliation of Newton's Third Law. Combining the standard conceptual aspect of the FCI with the new epistemological instruction showed that not only did our reformed class at the University of Maryland produce students that knew the correct scientific answer to the N3 questions more frequently than a traditional class taught by a capable instructor, a higher percentage of them also indicated that the correct answers made intuitive sense. The reformed students gave correct and reconciled answers roughly three times as often. Though numerically this result is more dramatic than anything I got from the MPEX2 data, its epistemological scope is narrower; it only says anything about reconciliation on a small subset of FCI questions.

The FCI split task is as easy to administer (though it takes slightly longer) to large numbers of students as the traditional FCI is, but it is harder to score. Each student has to give two answers for all the items, and doing that with electronic scoring is difficult. For my main results, I had to manually enter the responses. Also, the FCI split task is more vulnerable to students misinterpreting directions, even when the directions are made clear. I had students leave the last (back) page blank and others only give either just a circle or just a square as an answer. The verbose instructions do avoid the problems Mazur and others discussed, though. Students do not have to worry whether they should answer the questions as they think about them versus what is taught. With the split task, they have an option to differentiate those fully.

Case study interviews

Sandoval (2005) laid down an epistemological research challenge which was met in my case study chapter. I wanted to create interviews that were based on a specific tutorial context within our introductory physics class, and I was able to do that based on quick (but immediate) viewings of classroom videotape. The reason my data ended up as rich as it did was that the videos provided interesting conversation starters while the interview questions were able to probe issues deeper than the video alone can. When a student is working on a tutorial with peers, she might not have the time or willingness to put her thoughts out there.

My most detailed interviews and analysis came from "Patty," a student in Maryland's introductory mechanics class. I found that basing interviews on tutorial lessons she had just completed provided a direct and authentic way of figuring out what was going on in her class epistemologically. The relevant classroom context and longitudinal nature of the research are qualities Sandoval called for in a study.

To me, the most interesting finding associated with combining video and interviews was that I was able to contradict in the interview a finding that is apparent from the video. I have video evidence that points to the conclusion that Patty's group understood and reconciled a particular tutorial, and the interviews showed that the conceptual reconciliation did not stick nearly as well as I first thought. Not only that, but I was able to isolate a set of resources Patty activated in our interview contexts that might be a cause: she tended to see reconciliation as a simple manipulation of the language rather than a deep reorganization of ideas.

Future research directions

MPEX2-like surveys

Although I modified the MPEX to center it more on epistemology while maintaining the most important clusters, the survey is not without its problems. For one, I modified it to be appropriate for an introductory algebra-based class. Since I believe that specific context in a survey is very important, if the course context changes, the survey should change. If one wanted to go back to surveying engineering majors, he or she may need a new version of the survey. Also, since I have observed so much difference between an administered survey and an interview soon afterward, it is clear to me that individual students are very sensitive to changes in testing circumstances. The MPEX2 clusters reflect large instructional goals my research group had when we began studying introductory algebra-based physics students in 2000. Since the MPEX2 evaluates courses more than it does students, courses with different goals may require new surveys.

As with my section on the effect of modern physics on a class's epistemological attitudes, it might be possible to use it to compare the epistemological outcomes of using different instructional techniques and methods, for example, standardized versus epistemologically centered tutorials.

Split tasks

There is no reason that something like a split task should be restricted to the FCI. For our classes at Maryland, something like the FCI was appropriate because our instructional interventions occurred in a mechanics class. For other classes, the split approach can be used to probe reconciliation on other conceptual inventories.

Although I did not do anything approaching this for the present work, it is similarly feasible to devise a different type of split task for epistemological inventories as well. Gray et al. (2008) did this for the C-LASS survey at the University of Colorado, and they found that "students who have not yet taken physics in college have a surprisingly accurate idea what physicists believe about physics." However, their personal beliefs about physics are variable as they are entering introductory physics, and changes they go through depend a lot on the course they take. In addition to tracking individual students, such an instrument could also evaluate how instructors explicitly and tacitly communicate their ideas about which resources are productive to activate in physics class.

Of the multiple choice instruments given in PER, split tasks (as I have given them) are among the more difficult to administer because two answers must be given to each question. While it is possible to use optically-scanned sheets, the more complex directions will likely lead to more student errors and invalid data.

Case study work

By far the least immediately practical work for teaching large classes, the case study work done here has at least shown that rich and interesting information can be gained about students by studying videotape and tape-based interviews together. Since the videotape is from classroom situations, epistemological focus here is both personal and proximal. Since I interviewed only two students and carefully analyzed one, further work could be done simply be doing the same thing I did to other students (or groups of students) in other courses. Benefits of this work include understanding specific ways student epistemologies affect their learning and becoming better as researchers at coming up with contextually relevant questions from video.

These benefits inspire the future directions of case study work. I came up with my questions on the fly and they worked well in getting rich data, but the questioning process could become more formalized in future research. Also, we may learn some common ways students activate epistemological resources in physics class, and it will be important in the future to come up with a way to codify these statements. I was going more for a proof-of-concept of the method, so my focus was not on formal coding.

Epilogue: linking dissertation work to practical teaching work

My stint as a full time graduate student ended about three years before the final version of this dissertation, and although my formal data acquisition on student epistemologies ended there, I have had to deal with epistemological attitudes in physics frequently since then. I have taught honors and Advanced Placement physics at the high school level for the past three years, and that has forced me to rethink the place of my research with respect to actual day-to-day teaching.

My experience at American Association of Physics Teachers meetings has indicated that while there is a rich and lively physics education research community present, there is a much larger contingent of teachers in attendance that is more interested in practical matters, that is, "what can I do in class on Monday?" While I have not completely adapted that attitude toward more theoretical education research, it becomes a serious question at times in the classroom. My interview case studies taught me that with a keen eye toward videotape and adequate time to interview students, I could come up with data that richly tells us things about epistemology. However, in the classroom, judgments and interventions must be made and performed on a shorter time scale with a large number of students. If anything, learning to see epistemologically relevant moments on classroom videotape was good preparation for seeing that sort of thing out in the real world.

As a researcher, I always was somewhat disconnected with the students. Many professors whose classes I studied were not people I was working for, nor was I grading many of the students I interviewed. As a high school teacher, I have to wear the teacher hat at the same time as the epistemological evaluator hat. Also, since I am the one responsible for instructing students, giving out grades, and the like, my interaction with students is now far more personal and direct.

I am not trying to say I do not get epistemological information from the students, far from it. It just happens on a shorter time scale then, say, the weeks of interviewing "Patty." In fact, my students are not afraid to give very blatant epistemological indicators in front of class. In my honors physics class, I like to mix in conceptual questions as well as numerical problems that blend multiple ideas from across the course. One of my students complained that they wanted more questions where the object is to find the right equations and plug in numbers (there were already a small number of these, but you can never please everyone). I responded that I wrote the exams purposely to avoid that sort of thing, and he exclaimed, "but that's what physics *is*!"

That anecdote is one small example of how epistemological issues came up in my class all the time. Those moments were often tension-filled, and they only serve to illustrate how important it is to recognize potential disconnects between student beliefs and expectations and my own expectations and goals as an instructor. I never gave the MPEX2 or the FCI split task to any of my classes, but I imagine the pretest results would be similar to the introductory college students at Maryland. How those instruments would read at the end of the semester, I cannot say. I can say, though, that high school teaching has been less idealized than my teaching assistantships at Maryland have been. At Maryland, our PER-studying instructors could often pick their teaching assistants and assign two of them to teach one tutorial section of twenty students. I often have more than that in high school to deal with myself. Also, college students only have four to six classes to worry about (and those are not everyday) unlike the seven or eight my students typically take.

I am not saying that dealing with all the practicalities of high school teaching makes me regret my experience in a more controlled educational environment. I am saying that my work, say, with Patty's case study helped me not only with thinking of those kinds of epistemological questions on the fly while in class, but also being aware of what kind of conceptual/epistemological conflicts students can have. The point of mentioning all this is to set up this theory: the more work that is done in the style of my case studies, the more awareness we can build of how different epistemological reactions are elicited by different instructional contexts. I have learned some of this on my own by now, but maybe our field can do a lot more of this for other teachers out there.

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Appendices

Appendix A: MPEX2 items and notes

Chapter 3 discussed how items on the MPEX2 became what they are. This is the most recent list of MPEX2 items used in the PHYS121 class. The MPEX2 should be given as a pre and post test to an entire class before and after a semester of instruction. Ideally, the survey should precede any introductory lecture or presentation. A professor indicating that the class will “not be about memorization” or “will require deep and serious thinking,” for example, might skew the pretest results. In addition, it must be clear to the students that the survey is not graded. However, the surveys must be matched for pre and post tests. This is not to evaluate individuals, but to ensure that the same population is tested both times. Therefore, we always got their names with the survey, and offered participation points for completing it.

Since the survey is entirely multiple choice, a bubble sheet or optical scan form is the best way to administer it. However, some glitches can occur. The data tables should be matched by hand once they come in to account for name typos and changes from, say, a full name to a nickname. In some cases, a student bubbled in two answers. In those cases, I erased that response. In rare cases when students didn’t respond to many survey items (typically five or more), I did not use their data at all. We still gave participation points to students that did only a pretest or only a posttest, but if they did not do both, they were not counted.

Here are 25 statements (Items 1-25) which may or may not describe your beliefs about this course. You are asked to rate each statement by selecting a response between A and E where the letters mean the following:

A: Strongly Disagree	**B: Disagree**	**C: Neutral**	**D: Agree**	**E: Strongly Agree**

Answer the questions by filling in the bubble on the scantron for the letter that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple.

<u>If you do not understand a statement, leave it blank. If you understand, but have no strong opinion one way or the other, choose C. If an item combines two statements and you disagree with either one, choose A or B.</u>

Please do NOT write on this sheet. It will be reused. Make sure your name and ID# are on your scantron sheet IN PENCIL.

1.) Learning physics will help me understand situations in my everyday life.

2.) All I need to do to understand most of the basic ideas in this course is just go to lecture, work most of the problems, read the text, and/or pay close attention in class.

3.) The main point of seeing where a formula comes from is to learn that the formula is valid and that it is OK to use it in problems.

4.) When learning a new physics topic it's important to think about my personal experiences or ideas and relate them to the topic being analyzed.

5.) In this course, adept use of formulas is the main thing needed to solve physics problems effectively.

6.) Knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation.

7.) If I don't remember a particular equation needed for a problem in an exam I can probably figure out an (ethical!) way to come up with it, given enough time.

8.) Physics is related to the real world, but I can understand physics without thinking about that connection.

9.) "Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.

10.) In this course, I do <u>not</u> expect to understand equations in an intuitive sense; they just have to be taken as givens.

11.) When doing practice problems for a test or working on homework, if I came up with two different approaches to a problem and they gave different answers, I would not worry about it; after finding out the right answer, I'd just be sure to avoid the incorrect approach.

12.) My grade in this course will be primarily determined by how familiar I am with the material. Insight or creativity will have little to do with it.

13.) Often, a physics principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in physics is supposed to make sense.

14.) If a problem on an exam does not look like one I've already done, I don't think I would have much of a chance of being able to work it out.

15.) Tamara just read something in her physics textbook that seems to disagree with her own experiences. But to learn physics well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.

16.) The most crucial thing in solving a physics problem is finding the right equation to use.

17.) When handing in a physics test, you can generally have a correct sense of how well you did even before talking about it with other students.

18.) To really help us learn physics, professors in lecture should show us how to solve lots of problems, instead of spending so much time on concepts, proofs of general equations, and one or two problems.

19.) A significant problem in this course will be being able to memorize all the information I need to know.

20.) If physics professors gave really clear lectures with plenty of real-life examples and sample problems, then most good students could learn those subjects without having to spend a lot of time thinking outside of class.

21.) Although physical laws may apply to certain simple situations like we see in class and lab, they have little relation to what I experience in the real world.

22.) Group work in physics is beneficial only if at least one person in the group already understands and knows what they are talking about.

23.) When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written essay questions, but not for regular physics problems.

24.) To understand physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

25.) It wouldn't matter if I didn't get my homework returned to me as long as I knew which questions I got wrong and I had the solutions to study.

26.) Two students are talking about their experiences in class:

Meena: Our group is really good, I think. We often spend a lot of time confused and sometimes never feel like we have the right answer, but we all listen to each other's ideas and try to figure things out that way.

Salehah: In our group there is one person who always knows the right answer and so we pretty much follow her lead all the time. This is a great because we always get the tasks done on time and sometimes early.

(a) I agree almost entirely with Meena.
(b) Although I agree more with Meena I think Salehah makes some good points.
(c) I agree (or disagree) equally with Meena and Salehah.
(d) Although I agree more with Salehah, I think Meena makes some good points.
(e) I agree almost entirely with Salehah.

27.) In the following question, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other.

Tracy: A good physics textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate.

Carissa: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before choosing one.

(a) I agree almost entirely with Tracy.
(b) Although I agree more with Tracy, I think Carissa makes some good points.
(c) I agree (or disagree) equally with Carissa and Tracy.
(d) Although I agree more with Carissa, I think Tracy makes some good points.
(e) I agree almost entirely with Carissa.

28.) Let's say a student has limited time to study, and therefore must choose between the following options. Assuming the exam will be a fair test of understanding, and assuming time pressure during the exam isn't an issue, which option should the student choose?

(a) Learning only a few basic formulas, but going into depth with them.
(b) Learning all the formulas from the relevant chapters, but not going into as much depth.
(c) Compromising between (a) and (b), but leaning more towards (a).
(d) Compromising between (a) and (b), but leaning more towards (b).
(e) Compromising between (a) and (b), midway between those two extremes.

29.) Some people have 'photographic memory', the ability to recall essentially everything they read. To what extent would photographic memory give you an advantage when learning physics?

(a) It would be the most helpful thing that could happen to me
(b) It would help a lot
(c) It would help a fair amount
(d) It would help a little
(e) It would hardly help at all

30.) Consider the following question from a popular textbook:

"A horse is urged to pull a wagon. The horse refuses to try, citing Newton's 3rd law as a defense: The pull of the horse on the wagon is equal but opposite to the pull of the wagon on the horse. 'If I can never exert a greater force on the wagon than it exerts on me, how can I ever start the wagon moving?' asks the horse. How would you reply?"

When studying for a test, what best characterizes your attitude towards studying and answering questions such as this?

(a) Studying these kinds of questions isn't helpful, because they won't be on the test.
(b) Studying these kinds of questions helps a little bit, but not nearly as much studying other things (such as the problem-solving techniques or formulas).
(c) Studying these kinds of questions is fairly helpful, worth a fair amount of time.
(d) Studying these kinds of questions is quite helpful worth quite a lot of my time.
(e) Studying these kinds of questions is extremely helpful, worth a whole lot of my study time.

31.) Roy and Theo are working on a homework problem.

Roy: "I remember in the book it said that anything moving in a circle has to have a centripetal acceleration."

Theo: "But if the particle's velocity is constant, how can it be accelerating? That doesn't make sense."

Roy: "Look, right here, under 'Uniform Circular Motion' – here's the equation, $a=v^2/r$. That's what we need for this problem."

Theo: "But I know that to have an acceleration, we need a change in velocity. I don't see how the velocity is changing. That equation doesn't seem right to me."

31.) If you could only work with one of them, who do you think would be more helpful?

(a) Roy would be much more helpful.
(b) Roy would be a little more helpful.
(c) They would be equally helpful.
(d) Theo would be a little more helpful.
(e) Theo would be much more helpful.

32.) Several students are talking about group work.

Carmela: "I feel like explaining something to other people in my group really helps me understand it better."

Juanita: "I don't think explaining helps you understand better. It's just that when you can explain something to someone else, then you know you already understood it."

With whom do you agree? Read all the choices before choosing one.

(a) I agree almost entirely with Carmela.
(b) Although I agree more with Carmela, I think Juanita makes some good points.
(c) I agree (or disagree) equally with Juanita and Carmela.
(d) Although I agree more with Juanita, I think Carmela makes some good points.
(e) I agree almost entirely with Juanita.

33.) Why are you taking this course?

(a) I'm a biology major (not pre-med). It's required.
(b) I'm an architecture major. It's required.
(c) I'm a pre-med. It's required.
(d) I took it to fulfill some other requirement.
(e) Other:

34.) On a scale of 1 to 5, I would rate my overall experience in previous science courses as:
(A) 1: very negative (B) somewhat negative (C) neutral (D) somewhat positive (E) very positive

35.) I feel that my ability to learn physics is:
(A) well above average in this class (in the top 10% of this class)
(B) better than average for this class
(C) about average for this class
(D) below average for this class
(E) well below average for this class

36.) Compared to my ability to learn physics, my ability to learn other subjects is:
(A) much greater
(B) somewhat greater
(C) about the same
(D) somewhat less
(E) much less

37.) My previous physics experience is:
(A) none, I've never taken physics before
(B) one year in high school
(C) two years in high school
(D) something else

Original versions of the MPEX2 included a dialogue between Roy and Theo and left blanks for the student to write advantages of working with each. I want this to remain a concise, optically-scannable survey, so the original written item was eliminated. Also, the background questions changed from semester to semester. The confidence items can be eliminated if desired, as they are not formally scored.

The table below gives the final question breakdown across clusters and subclusters. Some questions involve student background and general science confidence. Those questions are not listed.

Cluster	Subcluster	MPEX2 items (by number)
Concepts	(no subclusters)	5, 9, 16, 18, 19, 23, 24, 27, 30
Coherence	Math	3, 10, 28
	Reality	4, 8, 15, 21
	Other	6, 13, 19, 23, 27
Independence	Epistemological	2, 11, 12, 20, 22, 26, 29, 31, 32
	Personal	7, 14, 17

Table A-1: MPEX2 items and their clusters

Appendix B: Interview transcripts used to make the newest MPEX

The acronym "OR" refers to the original response given on the scanned version of the survey. I partially measured test-retest reliability by comparing those responses to those given in the interviews.

Anne's interview

Interview: "Anne", MPEX2 survey, done on 5.21.02 at 11 am.

I: Alright, so, like I promised you…
S: We'll go over that…
I: Right, that's exactly right. We'll be going over the items on this, so we'll read through 'em, and you'll have a chance to give your response as to whether you agree, disagree, neutral, whatever, you'll have the same options as you had when you took it the first time, and each time if there's, if there's an instance where you want to give a reason why you think that, give that at the end, all right? I'll be listening for your responses, and if I hear something interesting and I want to
S: talk about it…
I: talk about it or hear an elaboration, exactly
S: OK.
I: That's precisely what we'll be doing. OK, so, there'll be a couple of general things at the end, but I think it's just best if we just… dive right into this, OK, so… (pause) let's see how we do here. You don't have to give letters, just say which of these.
S: Do I just say "1" or do you want me to say the actual question?
I: Oh, no, no, I'll read through what this is…
S: OK.
I: What the question is, just so I have it, so I know which one we're talking about, and then you just say which of these, and why, OK?
S: OK.
I: All right, so the first one is…
I reads question 1. (Original response (OR): agree)
S: Yeah. (laughs)
I: How strongly do you agree with that.
S: Um, I mean, I agree with it, not very strongly because, you know, there's a lot of other things that go on… biochemistry and things like that. But the physics of things is pretty interesting and it has helped me understand things. I was able to fix something in my house because of what I learned in physics class.
I: Really? What?
S: It was a, like, the batteries in my tape player weren't… I threw it, and it once wasn't working…
I: Mmm-hmm.
S: So I knew that aluminum foil conducts electricity, so I just put some aluminum foil in there and it worked.
I: Oh, so there was the problem with where the battery was contacting one of the metal pieces and you needed…
S: Like, it wasn't contacting it, so I put a conductor in there…
I: Oh, neat, neat. OK. Um, in what sense… you were hesitant. So that's a good example, but in what cases do you think it doesn't help you? I mean, you seem to agree with most of that…
S: I know, I just don't analyze everything in my everyday life.
I: Ah, I see.

S: So, if I were to do that, I'm sure physics would help me.

I: OK, um, all right, so, this is a question… like a number of others… related to the class, right?

I reads question 2. (OR: neutral)

S: Um, I mean, you have to pay a lot of attention in class, so… and working the problems did help, but I don't think reading the text helped at all, 'cause I pretty much didn't.

I: So would you say you disagree with the statement?

S: I mean, I agree with it, I would agree with part of it.

I: OK. Is there anything else you think that's important to understand the ideas in the course?

S: I think it's really important to relate it to what you already know, and I think… relate it to everyday situations.

I: OK.

S: That's what really helped me.

I: OK.

S: And, you know, reconciling, and seeing how things work.

I: Can you think of an instance where…

S: Um…

I: where that was useful? Relating it to something you already know… the way you put it.

S: Uh, well, going back to last semester, like, the idea of torque, thinking about how it works in a car.

I: OK, um, how did you think about it? What did you know about it before?

S: I didn't. (laughs)

I: Oh.

S: But relating it to how it worked in a car, um, you know, how everything is moving, and… seeing how it works in everyday life helped me to understand the concept of it.

I: Oh, OK. So that's not so much a connection with prior knowledge, but rather with a real life situation.

S: Right, so.

I: Fair enough. All right, so let's move on. I don't know how quickly we're going, but…

I reads question 3. (OR: disagree)

S: No, I disagree.

I: OK.

S: I usually, you know…

I: So what do you do?

S: I check with the TA (I laughs) and try to understand where I got it from.

I: OK, what if the TA's not around?

S: Then I wait until I can talk to… I talk to classmates, or… I talk to classmates or a TA to try to figure out, you know, how other people thought, to approach the problem, I don't just automatically say it's wrong or try to trust it then.

I: OK, all right. So here's something related to something Dr. [PER professor] did in class a lot.

I reads question 4. (OR: disagree)

I: So he, he showed you where a lot of the formulas come from, so do you agree with this statement (paraphrases the statement)?

S: Well, not really. It's… like, the essay question on the final exam. It's important to see where it comes from and how to use it, but I think it really helps you to better understand what's going on with the equation, if you know the derivations. Like, um… like the Coulomb's equation, F = kcqQ / r.

I: Qq over r squared.

S: You go through that, like, you think about how the charges are interacting and everything, then, I think it helps. I mean… (pause) I don't know how to explain it, I'm sorry.

I: No, that's fine.

S: I just think it helps to see where everything's coming from because it gives you a better idea of the bigger picture.

I: That's a fair statement. I was just a little confused when I first heard what you were talking about, cause Coulomb's Law isn't one of those things we can derive.

S: No, no it's not. That was my mistake, I'm sorry.

I: No, that's fine. Which equation in the final exam…

S: I used Coulomb's equation.

I: OK, did you…
S: I didn't say it was a funda… I said it was a fundamental principle because we weren't really deriving it from anything.
I: We didn't derive it, yeah. F=ma and the gravitation rules are the same kind of thing. OK. So, let's see, what's next.
I reads question 5. (OR: strongly agree)
S: Yeah, I strongly agree with that.
I: Strongly agree, all right. I think you've actually already talked about that.
S: Yeah.
I: All right, so we move on
I reads question 6. (OR: disagree)
S: I'd say I'm neutral on that. It does help because you do know when you need to use the equations, but a lot of the time, like, going into the final I didn't really memorize all the equations and I don't think I did badly, because I understood the concepts behind them.
I: OK, so you said you didn't memorize all the formulas, but you were able to solve some of the physics problems using something else?
S: Yeah.
I: OK. That's pretty useful. Um, but… people have their own strategies for dealing with problems, and that's why we talk to them, and give them surveys, and stuff.
(S chuckles)
I: We can't assume that everyone is the same, we get a lot of people that are very formula dependent, and if they have all the formulas and they memorize 'em, they'll do fine, but…
S: I was like that, but after this class, not so much anymore.
I: Oh, you're not? OK, well, I guess that's good. I think that was one of Prof. [PER prof]'s goals, but in any case…
I reads question 7. (OR: disagree)
I: Do you agree with that?
S: Um, yeah. I would agree with that. You know, it doesn't apply primarily to just one situation, it can apply to many situations and, you know, there's pieces of physics in like… there's different, I don't know how to explain it… Like, you can always relate it back, most things back to the fundamental principles of, you know, velocity, and F = ma, and Newton's laws, and things like that, but, if you're going into electricity and magnetism, a lot of them are more specific.
I: OK, so you're saying for electricity and magnetism, the principles don't apply to as many physical situations.
S: Right.
I: OK, but you get a wide range of applications for stuff, say, you learned first semester?
S: Yeah.
I: Did I catch that right?
S: Yeah.
I: OK. So, here's… the next one maybe relates to something you said about the final.
I reads question 8. (OR: agree)
S: Yeah, I strongly agree with that.
I: OK, were you able to do that on the final at all? Where you just forgot an equation but were able to come up with it?
S: Yeah, like the Maxwell's rainbow equation, where I equals I 0 cosine squared theta. It was the last page of the short answer.
I: Oh, the...
S: I didn't remember what it was, but using the, like, I couldn't remember it exactly, but using what he told us, I was able to figure it out, and like...
I: This is for the polarizers?
S: Yeah.
I: What did he tell you that helped?
S: He was giving me the angles, and, you know, the initial intensity, and I knew it had, but I wasn't sure if it was cosine or sine, so, I was working it out.
I: Oh, right, OK. That's fair, all right, so let's move on to the next one, what's that?
I reads question 9. (OR: disagree)

S: I can't understand physics unless I relate it to the real world.
I: OK.
S: Or at least I have more difficulty unless I can apply it to a real situation.
I: OK. OK, that's fine. With there any parts of the course where, uh, you had more difficulty making the connection to the real world?
S: Uh, I had problems with some of the magnetism and light, because even though you know, light is everywhere, the lenses and, you know, where the lines were going kinda got confusing to me, and the focal points, and all that.
I: Drawing the rays? That doesn't seem...
S: Yeah. That wasn't as applicable, so I had more, at least I didn't make the application in my head, so, it was a little bit more difficult.
I: Think that had something to do with the difficulty you had with the ray problem?
S: Yeah.
I: You were telling me that...
S: I mean that...
I: the last one on the final gave you trouble.
S: Yeah. I mean, I knew all the appropriate rays to draw, I just wasn't sure what happened with that, with the lens that was there, and how to make that work.
I: You mean, your eyes, you see stuff, but you don't picture it as actual rays.
S: Right, it's harder to think about it that way.
I: That's fair. When I was supposed to write an essay about some physics related thing, many many years ago, I talked about how the study of sound, light was appealing because these things are, of course, all around, and you have a lot of experience, but the way they're talked about in class is often a little different.
S: Yeah.
I: than...
S: You just have to...
I: Rays on paper are more abstract, I think, then what you're used to dealing with.
S: Yeah, because on like that equation that I was trying to think about, well, if it's a convex lens, then think of it like a glasses, because most glasses are convex, or like a magnifying glass or something, and I was trying to think, if you hold the object up and you're moving it around, how is it gonna look? And I just had a really hard time applying, even though it was concave.
I: All right. So, last one on the first page.
I reads question 10. (OR: disagree)
S: Not in Dr. [PER prof]'s class! (Chuckles)
I: Um, OK.
S: You use, he makes you... I think physics is one of the more difficult sciences for people, cause you have to use common sense and real world experiences, and you can't just use your equations and the fact that they tell you in class, like, you actually have to think about things.
I: OK, so are you disagreeing with the statement, then?
S: Yes.
I: OK. Do you, did you have experience taking physics before this course?
S: I took in high school.
I: OK. Did you have the same experience in that class?
S: He, when I took in high school, it was pretty much all equations, and everything like that, and I never really understood anything that was going on, but I was able, you know, I can plug anything into an equation and get an answer, so I did well in the class.
I: OK, so, your impression on this item has changed?
S: Yeah.
I: You think? Over the course of taking this... I forgot, you had him last semester right?
S: Yeah.
I: So you had him for a whole year. All right, that's a long time, us TAs get to know you after long. I had about four students that had me both semesters.
S: Oh, really?
I: Actually, they were sick of me. All right, so what's next?
I reads question 11. (OR: disagree)

S: I think it's, I would disagree. I think it's, if you don't... I have problems if I don't understand it in some, intuitively, or try to figure it out. I can't really use them well. You know, if I don't understand how things are working and how I should use the equation, and if it's not fundamental, or if it's not fundamental where it comes from, then I can't really, and then I have a lot of problems with that.
I: OK.
S: So I can't just take things as givens.
I: Can you think of an equation that you were able to really understand in an intuitive sense? In a way that helped you solve a problem with it?
S: The, on the first exam, the very last problem where it was accelerating it through, um, a quarter of, I can't remember what it was.
I: You were accelerating a charged particle through a circle.
S: And, yeah, you had to derive the, like, he made you derive the equation from, on the problem, even.
I: Uh-huh.
S: I understood that a lot better, I can't remember the equation right now, which probably reflects poorly, but, it was from F equals m a, and m v squared over r, and, it was m v over c B, I don't really remember it now, but...
I: The details aren't important.
S: But going through that helped me to understand how the problem was working.
I: What about that did you understand in an intuitive sense, though? I mean...
S: Like, I, if you break it down to the fundamentals, I have a better idea intuitively of how things are working.
I: OK.
S: Sorry.
I: What you apologizing for? It's fine. All right, so let's see what's next.
I reads question 12. (OR: disagree)
S: Oh, that's similar to the one on the last page. Um, not that I...
I: So, yeah, what's your reaction to that statement?
S: Well, if anything, I've learned from this class that, you know, there's good and bad things to every approach, and so it's important to look at how I came up with both approaches.
I: Mmm-hmm.
S: and what's good about each one and what's bad about each one, so I can understand what's the best way to approach the problem.
I: OK, but what happens when you try two approaches and you get different answers?
S: I check with the T. A. or someone else in my class. (Chuckles) again, I try to think about how, what made me come up with the two approaches.
I: OK, so, so suppose you've got two approaches, and then you find the answer from someone else, right? Like the question says. If you look up the right answer, and you see that one of your approaches gave the right answer, and the other one didn't, what do you do then?
S: Then, I try to figure out how I got, like why I got the wrong answer, you know, what was wrong about my thinking, and if I was even remotely on the right track, and then I use that in future problems.
I: OK, all right. So, let's see, what's next? I guess you don't really know your grade in the course, but what do you think about the statement...
I reads question 13. (OR: disagree)
S: Well, since our grade in the class is pretty much strongly determined by our labs, and our homeworks...
I: Uh-huh...
S: It's kind of both, you know? It, you need to be familiar with the material to do well on the homework, but, in order to do well on the labs, a lot of the time you really need insight and creativity to figure out, at least for... for the modeling labs, to come up with a creative model for how things work, and for the measurement labs, to figure out what's a good way to measure this, you have to be creative. So I think it's both. And in order to be creative, a lot of times, in figuring out how to do an experiment, you need to have a good knowledge of the material.
I: OK, so...

S: So I would disagree with that statement, because insight and creativity are probably equally as important...
I: Equally as important, OK. All right, so what about this one?
(199)
I reads question 14. (OR: disagree)
(S. chuckles)
S: Not everything in life is supposed to make sense. I have, like I said, I have a hard time, if I don't understand something, I can't do the problems on it, and if I can't do the problems on it, and I'm not gonna do well in physics, so...
I: OK.
S: You know, I would disagree with that.
I: All right. Have you ever been instructed in a theory, or principle, or equation, or what ever, that you didn't understand and you had to just accept it for a little while?
S: Um...
I: Has that ever happened? I mean, you disagreed with the statement, but, are there any...
S: Yeah, I mean, I can see it, like, doing my finals now in a lot of my other classes, where professors will just throw out something, or they'll start to introduce topics before you really understand what's going on, if you're looking back it all makes sense, because they finally explain everything through it, you know? Does that make any sense?
I: OK, I'm just trying to relate what you just said to the physics course.
S: Right.
I: Right.
S: I'm not sure if he did that... just said "hold on."
I: I mean, did everything...
S: Everything...
I: Did everything make sense the first time he explained it to you?
S: No. No, I mean, in the lab we needed a lot to help make sense, I think the labs were a major part of my understanding in the class.
I: Really?
S: Yeah.
I: Well, OK, that's good, maybe the T. A.'s aren't totally useless.
(S. chuckles)
I: In any case, you knew about this, right? I think the labs are 25 percent of the grade...
S: Something like that.
I: So, each lab report is worth nine, and this is off topic...
(I and S. discuss irrelevant lab stuff)
I: OK, where were we? All right, OK, this next one...
I reads question 15. (OR: neutral)
S: Um, that probably relates to something later on on this thing that I remember, um... I can try to figure it out, and usually I do a pretty good job of trying to figure it out with what I already know, but sometimes it's hard and I really don't understand why, but a lot of people, myself included, just have problems, you know, you can understand what's going on in the class, but it's hard to apply it to problem situations.
I: OK, so, do you agree with the statement? I mean, how good do you think your chances are of being able to solve it if...
S: I'm pretty good at being able to solve things if, if I don't, so I would have to say I don't, I disagree.
I: OK, you disagree, but you don't think that you have a chance to solve that, right? Trying to work the double negative so it works right...
(S. chuckles)
I: Get the proper meaning across, all right. So, next...
I reads question 16. (OR: disagree)
S: I disagree with that.
I: OK.
S: You know, there's a lot of times in class where he just... at least, I remember a lot more in first semester when he'd say, "well, what's your own experience on this?" And, like, with the gravity, when

you jump off a diving board, and, like, thinking about how astronauts float in space...
I: Mmm--hmm...
S: and he made people relate it to jumping off a diving board and holding something in your hand at the same time, if you let go, you're both falling at the same rate, so it's like you're both floating, so that, you know, that's why astronauts appear to float, because everything is falling at the same rate. So, back to the question...
I: No, no...
S: I just think that if you relate it to your own experience of jumping off a diving board...
I: Had you done that before? Jumped off a diving board, and held something?
S: No, but I could picture it because I've jumped off a diving board.
I: OK. Here's another interesting trick. Have you ever been on any of those free fall rides at amusement parks where they just drop you?
S: Yeah. I hate those things.
I: if you put a coin on your leg, as soon as you drop, it lifts off a little bit and floats above it while you're falling.
S: Oh, that's neat!
I: Yeah, yeah. We had this... my high school physics classes went to the amusement park a couple times, so we observed that kind of stuff.
S: Oh, you guys are lucky, we didn't get to do that.
I: They're good trips. Yeah, I went twice, it's an argument for taking physics and AP physics, you get to go on the roller coasters twice.
(S. chuckles)

I reads question 17. (OR: disagree)

I: do you agree with that?
S: Um, I'd say.. I agree with it to some extent. Because if you don't have the right equation, a lot of times you can't just solve the problem, but I think it's important to think about, I mean, thinking about it and having... you have to think about a lot first, and, like even with problems, you can come up with the equations if you think about it enough, so... but if you don't have, if you can't think about it, and get that equation, you can't often solve the problem, you know?
I: OK, OK. So, getting the equation is important...
S: It's important, but I think thinking about it is more important, so I guess I disagree.
I: OK.
S: It's not the *most* crucial thing.
I: I guess that's what the wording says, it's asking if you agree with... the *most* crucial thing is to find the right equation, all right.

I reads question 18. (OR: neutral)

S: I was actually talking to other people after the final yesterday, and, you know, everybody tends to feel like crap after they come out of a physics test, and I'm not really sure why.
I: OK...
S: they always think they did poorly, and...
I: Right.
S: I always think I did really poorly, and that's not always the case, so, I guess I have to disagree, that I don't have a correct sense of how well I did.
I: Because you think you did badly, and ended up doing fine? OK. You think you did fine on the exam yesterday?
S: I don't know. I knew I could answer everything, and there wasn't anything I just... except for the last problem that I didn't blatantly not know how to do, so I don't think I failed it, but I really don't know anything other than that.
I: OK. I mean, we could check that later, like I said, the exam is practically done, I mean, most of us have graded our problems, and we'll all be done by the end of the day, and I'll show you how you did on that last one if you want.
S: Goody.
I: what you don't want to do is being that one person, you know, you have this group of people talking to each other, and feeling like crap about the test, and you go up to them and say, "oh, that test was easy, I did great!"
S: Yeah, I find if I think I did well on the test, I usually did worse than I thought I did, so...

I: Well, even if you did well, you don't want to brag about that to a bunch of people... I've seen that happen in grad school a couple times, I haven't done this personally, but, I know what it's like to be on the negative end of that. Let's see, so next...

I reads question 19. (OR: neutral)

S: Um, well, in this class, he spent more time on the concepts and proving, and didn't really do a whole lot of problems, and what office hours were for was helping us figure out a lot of the problems. And...

I: OK.

S: I think what I learned a lot from is... class is probably like 40 percent, and office hours are 60 percent, because...

I: 40 and 60 percent of what?

S: Like, my... how I understood physics.

I: Really?

S: Yeah. Well, because, not necessarily understand it, but being able to do well in the class... because, I got to see how individual T.A.s and even Dr. [PER prof] approached the problems, so, seeing how they approach problems and what they're thinking was, helped me to do that. Like, helped me to understand and figure out things better. So, I kinda wish we had done more problem solving in the class.

I: So, you think that he should do more...

S: Yeah, but I also think, you know, focusing on concepts and the general equations is also important, it's just... if we're not directly tested on them, it's... I find it harder to, you can understand the concepts but it's harder to apply it to a problem for a lot of people. And, so I think it's important also to see how to approach different kinds of problems.

I: All right. So, that was a good side conversation, so what's next?

I reads question 20. (OR: disagree)

S: I disagree, but the only... I didn't have to memorize a lot of equations, and I didn't have to memorize a lot of stuff to be able to do well in a lot of the classes. The only problem with what... on the first test, there was the estimation problem...

I: Uh-huh...

S: and, they told us all the equations, said "know all these equations," and I blatantly memorized all those equations and end of one equation that I don't know where it came from, because it wasn't what [TA] or Dr. [PER prof] told us to know, that power equals wattage over time, that was how you got that, that was how to figure out that answer.

I: Oh.

S: so, like, yes, I would agree with that overall, but there are instances where you do need to...

I: OK, OK.

S: That was one of those unfortunate situations.

I: So, yeah, counterexamples are good, if you have an opinion about one of these, we go through it, and then you think, "but, you know, there's this one time where something else happens..." and you go ahead and say that too, I mean, I'm interested in hearing about all of this stuff.

I: All right, next.

I reads question 21. (OR: agree)

S: Uh, I would disagree, I mean, anything to understand physics at all, you really have to think outside of class, it doesn't matter how good the professor is, because a, you don't pay attention on the times in class, and...

I: What, you don't't?

S: Yeah, I know. And, you know, not everybody pay attention, or, you know, you just don't quite grasp it, no matter how clear the professor can be, so, I think it always requires some sort of thinking about it outside of class.

I: All right. Moving on then...

I reads question 22. (OR: disagree)

S: I disagree.

I: OK. (Pause) Can you think of a case... I mean, you gave me the sample earlier of using aluminum foil as a conductor, OK? Um, was there another instance maybe you can think of where you are able to, uh, apply a physical law to a more complex situation that you can think about in the real world and not in physics? I mean, in physics, we like to simplify stuff...

S: Yeah, I mean, I can't think of it now...
I: OK.
S: You know, there are times, especially for find something really interesting that I'll inform unwilling participants, such as, you know, my parents or friends, "You know, the physics behind this is really cool, and stuff..." But I can't think of any of them right now.
I: Right.
S: They'd probably walk away.
I: Physicists do like to simplify stuff, become a joke is that, you know, even when we talk about cows, we assume that a cow is a sphere just to make the math, just to make the math easier. All right...
I reads question 23. (OR: disagree)
S: I disagree, because, like, last semester I started working with <name> who's my lab partner this year...
I: Um... I don't...
S: It, it doesn't matter. But she doesn't generally, like, Matawan was really understood what was going on, and talking with each other and trying to work it out, both of us ended up, you know, being able to understand it. So, that's instance where you can be in a group, and not have everybody understand what's going on...
I: But it's beneficial to talk about it anyway? OK. All right, I hope to get a variety of impressions about that from people, we have all sorts of groups, I mean, we had groups that were two or three people that were, you know...
S: On the bottom...
I: They knew a lot of the stuff beforehand even more, I'm saying. Just about anyone had the potential to get it, but, they had seen it before, like in a previous physics class, and then we had other groups where, where...
S: (interrupting)??
I: there were just struggles all around.
S: Our discussion group was like that last semester. In discussion, none of us had any idea what was going on, but we discussed a lot, and were able to figure it out, it just took us a lot longer than with the other groups. But I think that was better, because, you know, if someone just tells you, "this is the right answer," I don't know, you can't just take it at face value, I think it's better to discuss it, and argue it, and try to figure it out, which is what we ended up doing.
I: Did you, did you think this sort of thing happened this semester?
S: Uh, well, we didn't... no, cause most of us just wanted to get out of class so we weren't really... at least, people...
I: Why the difference?
S: there was a person in our group who was not myself who just wanted to get out of class and wasn't really in, kinda, put a negative spin on the entire group.
I: Really?
S: So we didn't get to really get through a lot of stuff.
I: Tell me who it is, I'll give them an F... no... I don't want to know, I don't want to know.
(S. chuckles)
I: That's <TA's> job to give you participation grades, not me. OK, so let's see. That was the end of the second page, and there are a bunch more pages, but the questions take up more of the page, fortunately, so I think we're more than halfway done... (checks tape status... considers whether to continue)
I reads question 24. (OR: disagree)
S: I think understanding the big ideas was helpful for me, to, you know, to come up with methods to solving problems, so, I disagree.
I: OK. Um, would you say strongly, or no?
S: Sure. I'll be strong about that.
I: Sure. All right.
I reads question 25. (OR: disagree)
S: I would disagree with that, maybe even strongly. Um, you know, like I said, I didn't need to know the equations to go into the exam, I don't think I did, I don't think I failed the exam.
I: (diabolically) We'll see about that.
(S. chuckles)

I: All right.

I reads question 26. (OR: disagree)

S: Well, um, I guess I should be neutral on this, because I didn't use, I look at the solutions to the homework problems, and I didn't look at my own homework when I studied.

I: Oh, you didn't?

S: Because it was all jumbled up in the bottom of my book bag, and I didn't want to go through it all.

I: Oh, right, OK. OK. So, you actually didn't look at it at all, so, you don't really know what good that would have done? Do you think it would have helped?

S: It might've, but, like, but I don't know, cause a lot of the times I just couldn't remember what, how I came up with an answer, so I just look at how they came up with the answers, and, you know... so this is how you're supposed to do this.

I: OK, so let's see, we're doing the conversation stuff, so, let's see...

I reads question 27. (OR: A)

S: Yeah, so Meena is our group last year...

I: Uhhuh.

S: And, so, whatever...

I: That's Salehah, I think.

S: Salehah is the one girl, sorry I said girl, I gave you gender, the one person in my group this year. I would agree mostly with Meena, because I think I learned a lot more when we were discussing and arguing, like, things we didn't understand and working it out, even though it took longer, I enjoyed it more, because I got to really understand what was going on.

I: Do you think Salehah made any good points at all, or do you completely disagree with what she said?

S: No, I think it's great to get the stuff done on time, and sometimes early, but, you know...

I: Right.

S: I, I, if I... I guess if you had to say in our group, like, the one person who knew the right answer, and they followed her lead was kinda me, and I don't like that too much, because, you know, I'm not right all the time, so, I guess I'd have to disagree with that.

I: You don't like being the leader?

S: No, but I just don't like... yeah, I'm not right all the time, and I don't want them to just take everything I say at face value, just blatantly agree with it.

(Off task -- discussion of the foreign names in the last question.)

I reads question 28. (OR: B)

I: So who do you agree with?

S: I agree more with Tracy, but Carissa makes some good points. Like, it's... a lot of things relate to one another, but at the same time it's good to keep them separately, just so it's easier to break them down, you know, as far as understanding them goes.

I: OK, so, so that's what I was going to ask, but I think you just addressed it, how was it helpful that... some books separate things when you're studying? How is it useful to you, if you have a book that keeps everything in separate pieces?

S: Well, I think it's... all right, I'm not going to answer your question, but I will eventually, I'm gonna be a politician for a second.

I: OK.

S: No, I think it was better to read the books, and say, "oh, well, it's related to this and related to that," and that helped me understand it better, but if it's broken up into certain chapters, like a chapter on electricity, a chapter on magnetism, things like that, then, that was just easier for me to read through that chapter with references to other things in it, you know? So, separated in that way, but still containing references to other... how it's related to other things in physics.

I: OK, which book did you use for this semester?

S: I didn't really use the book.

I: Oh, you didn't?

S: I had, I bought the first Dr. [PER prof] book, but I didn't really use it, and I got the handouts, and I read the handouts, but I didn't buy the second book, so didn't really use the book.

I: So you didn't use it much at all the second semester?

S: No. I didn't really use it in the first semester.

I: Oh, really? OK. I think I'm going to switch this...
(start side two off task)
I reads question 29. (OR: E)
I: So, why don't you read the choices?
S: All right, so for my physics exam, I had three tests the other day, so I had a limited time to study for it.
I: OK.
S: Um, I assumed the test was fair, and we certainly didn't have time pressure...
I: OK.
S: I didn't really, I didn't really, like, I learned... I compromised between the two, I'd say. You know, I took a couple... I didn't really just, like, I was focusing more on trying to understand the concepts, so I wasn't really just learning formulas.
I: So did you, did you lean towards one or the other? Cause the last three choices all involve some sort of compromise...
S: I compromise, and I was midway between both extremes.
I: Midway between both? All right. All right.
I reads question 30. (OR: C) <I interrupts the question to ask if S. has been photographic memory. She replies, "pretty much," but insists it isn't perfect. I continues.>
I: So, to what extent would photographic memory give you an advantage when learning physics?
S: I don't think it helps, I mean, you can... because you have to think about it outside of class, or else you're not gonna, like, I could remember everything he says, he ever said in class, and still not do well on the tests, unless I think about it on my own.
I: So, do you equate doing well in the tests with learning physics?
S: Yeah. Well that, that's how you, that's how we're graded, that's our representation to the University and everybody else.
I: You're starting to use his terms, he's really brainwashed you, hasn't he?
(S. chuckles)
I: OK.
S: Yeah, I mean, it would help, but it's just not that much.
I: OK.
I reads question 31. (OR: D)
S: It's Mr. Ed.
I: Yes, obviously. You just have to go right to the source and ask the horse.
I continues the question, he phrases the last sentence as "Would it help you to study questions like this one?"
S: Yeah, I definitely... I strongly agree with that. Um, even though that's not one of the answers...
I: is?? OK, so...
S: Yeah..
I: We're sort of, sort of out of that ... but I guess strongly agree is closest to this one. (Referring to choice E)
S: Yeah, I'd say it's extremely helpful and, you know, good to focus a lot of time on that, because you're trying to figure out how, you know, you have to really think about Newton's third law here, and how it works, and there's, you know, there's a challenge to the law, and so you have to try to reconcile that in your head, and that's a lot of what he tries to get us to do.
I: OK. Can you think of the question like this that you studied that was useful on the exam?
S: Uh... no.
I: It's quick, it's on the spot, I mean, you haven't thought a lot about this before I asked the question, but I have to ask anyway, so...
S: Sorry.
I: No, that's fine. So, let's see, read the Roy and Theo debate.
I reads question 32's dialogue.
I: So what are the advantages of working with each of these people, judging from the style in which they speak to another?
S: Well, Roy's a know it all...

(I. chuckles)
S: Like, the advantages of... for him is that, you know, he has a photographic memory, he knows the equations, so, to some respect he, in some respects he knows what he's doing.
I: OK.
S: So you can learn some things, instead of reading the book, you can learn things from him.
I: OK, so what about Theo? What about working with him?
S: Theo, I think it's more advantageous to work with him because he's questioning things and challenging things, and, you know, not just taking everything at face value, and so you really understand it better.
I: OK, I think that was the next question actually.
I reads question 33. (OR: C)
S: Mostly Theo, but some Roy.
I: But some Roy, OK.
S: don't want him to feel left out...
I: We don't care about his feelings. Roy's just a fictional character, so we can hurt his feelings. Um, some group work...
I reads question 34's dialogue. (OR: B)
S: I agree mostly with Carmela, but Juanita makes some good points. I think explaining, explaining something to other people helps you really work it out in your head, and once you work it out in your head, you know that you understand it very well.
I: OK.
S: So, then you know that you already have the stuff, you already... you probably could have... I don't know. I agree more with Carmela than...
I: What do you like about what Juanita said?
S: Well, I was going to say that you know you already understood it, but... you don't really know you already understood it, so, I agree more with Carmela.
I: All right. So, let's see... almost done, I think. Some of these are going to ask you because they're background questions and so forth. All right, so what about this?
<I reads question about how students come away from a lecture feeling like they understand a given topic, but get stuck on homework problems.>
S: it's happened to me every single time, and I think that's why so many people end up going to the office hours, because even if they do understand something in class, they just don't know how to apply to the problems. So, I really don't know why it happens, maybe we don't have... because it's... you can understand something, but it's harder to apply to a problem because there's a different type of thinking that goes along with it, you know?
I: OK. OK, but office hours helps?
S: Yeah.
I: All right.
S: Cause I think it helps to see how other people approach a problem.
I: OK, so... will you be in your chosen profession to years from now? What year are you?
S: I'll graduate in December.
I: You're graduating in December, so what are you going into, do you know?
S: Neuroscience.
I: Oh, neuroscience? Have you told Dr. [PER prof] this? He's very interested in...
S: We've had many conversations.
I: He's very interested in neuroscience.
S: He actually knows about the research I'm doing now, which kind of made my jaw drop.
I: Which is on what?
S: Uh, synaptic... the changes in synaptic composition over the course of development, and the effects of growth factors on that.
I: So it's developmental neuroscience?
S: Yeah. Synaptic biochemistry, so...
I: OK, I don't know, I don't know the field, and I don't know what he knows either, but that's interesting. Um, is there anything in this class you think will help you with that?
S: Um, I think the labs definitely help, because...
I: How so?

S: I mean, I'm... I work in a lab, and I will be working lab, and I think one of the best things about the class is the lab, because it's not traditional, and he actually have to think about... more so the model... or, not the model, more so the measurement labs, because you really have to think about, OK... some of them are easy, and you're just like, "all right, well, I could do it this way," but you really have to think about different ways and what's the best way to approach a topic, and have to get the best data, and, you know, how to account for that, and presenting to people, and I think that's really helpful.

Background (original 35-59 are B, A, D, C, B)

I: Excellent, cool. All right, so... so you took Dr. [PER prof] for 121?

S: Mmm-hmm.

I: Right. So, you're neuroscience, is that a premed field?

S: Well, it could be, but I'm not premed.

I: But... you're not, you're not premed, this course was required for... what is your degree going to be in?

S: Physiology/neurobiology.

I: Neurobiology? So, this class is required for that major?

S: Yeah, it's required for the... all bio majors.

I: OK. So, yeah, what is your impression of other science courses, your experience in other science courses?

S: Uh, pretty much positive, because other science major, and it would suck if I hated all my classes.

I: Because, because you like science, OK.

S: Yeah.

I: So, just briefly comment on the last two. Your ability to learn physics, where do you think that is compared to the rest of the class?

S: Um, well, it depends on the topic...

I: Just in general...

S: Probably just a little bit better than average.

I: A little better? All right. Um, now the last one, do you think you're able to learn other subjects better or the same or worse?

S: I'd say a little better in other subjects, but that's why I'm not become a physicist. Yeah, if I were better in physics and I was in biology, then I wouldn't be a biology major... (interrupted)

I: So, so you're saying you're better at learning biology?

S: Yeah.

I: OK, OK, well, that's probably a fair statement. OK, so that's the general thing. When you were actually taking this, back when we were giving the survey out, Um, what was your impression of it? Do you think you're able to answer honestly and...

S: Did you give this out the first day of class?

I: We gave the same survey out at the beginning of class, yes.

S: OK, because in the beginning I was like, all right, well, I know what Prof. [PER prof] wants us to answer for these questions, and I put a lot of those down instead, but at the end, I put a lot of what I really thought down.

I: Oh, so, HMM. So even though the first one wasn't graded, you wrote down what you thought...

S: Yeah.

I: How did you know what he wanted to hear?

S: Cause I had him for 121.

I: Oh, I'm an idiot. (Both chuckle) Did you take it at the beginning of 121?

S: I can't remember, probably. And so, I didn't... you know, you?? A lot of this... from his first lecture and way he teaches, you can kind of understand what he expects out of us, and teaching the class, so, you can answer the questions based on what he wants very easily.

I: OK, so...

S: I mean, if you look at the end of the semester ones there are more...

I: Now that you've taken this about three times, are the questions on hear that you thought were vague or you had difficulty choosing a response?

S: Um...

I: You don't have to go back and pore through all of them, necessarily, but are their just any that

come to mind, that you just weren't sure how to address it?
S: No, I mean, they asked almost the same questions a lot of times in, like, slightly different ways, but there wasn't anything that was vague or...
I: OK, so, do you think taking this was a waste of time or not?
S: Well, it didn't help me, but it helps you, it helps the class probably, I hope.
I: Well, we hope so too.
S: You wouldn't make us do it four times if it...
I: Yeah, well, the only reason it's done this way is we... you had to take it four times as because you took [PER prof] twice, not because we think there's anything particularly special about you or anyone else who took him both semesters, but we do the things to see how the course affects these attitudes and responses towards the questions, and so that's why we have to get the same one before and after so we can see the change. If we did it any other way, the data wouldn't be reliable...
(interview winds down. End)

Bruce's interview

Interview: "Bruce", MPEX2 survey, done on 5.29.02 at 2 pm.

I: So, now that I've moved my chair along and made a lot of noise on this thing, let's take a look at this, and get started with it.
S: OK.
I: So, OK, No. 1.
I reads question 1. (OR (original response): strongly agree)
S: Uh, I definitely think D, agree.
I: You agree?
S: Not strongly, but, like, agree enough because, I know from, like, a personal standpoint, I'm kind of interested in how stuff works, and like, like, it'll help me out in the fact that, like, if I'm working along, and I don't understand why, you know, like, for instance, like, when we learned in lab about, like, very first semester that, the cars, and stuff like that, like, how it's not... but one has more force, it's equal forces. But it's all about the momentum, and, like, the acceleration change it would be F=ma and although the stuff, and it's like, kind of like appeals to me in that certain sense that I understand exactly what's going on there.
I: Oh, OK. OK.
S: You know what I mean?
I: Yeah. That's often an example people talk about when they think about something interesting they saw in the class...
S: Yeah, yeah.
I: Um... so, what sort of everyday situations did that help you understand?
S: Um... apart from that one, like, the whole... a lot with the light stuff, like, learning about... I mean, we all learned back in high school about, like, angle, like, reflection and infraction, like, all that other stuff. But, like, but understanding how it works, how it can work on different levels, how it works on waves... and then, like, just, once again it comes back to just, like, understanding the scope of everything, like, understanding exactly why does something behave this way, is kind of how it affects me in everyday life, it's not so much that, like, I apply it to something new, but just be able to comprehend something overall, you know? Like, understanding how exactly light works, and why it behaves such... like that, and like other waves, and stuff like that. Like, when you go to the doctor and get an x-ray, what exactly is going on there? You know what I mean? It kinda gives you almost a sense of security.
I: Mmm-hmm. OK, all right, good, then. Let's see what's next.
I reads question 2. (OR: neutral)
S: Uh, probably disagree with that.
I: OK.
S: Um, definitely, definitely need to read the book, and, like, understand the problems, and pay close attention class, but without the, uh, lab stuff, like, without the discussions in lab, you definitely

couldn't... you wouldn't be able to, like, comprehend everything, like, I can read something in the book, I know this me for personally...

I: Mmm-hmm

S: I can read something in the book, and, like, get a sense of it, but, until I see it applied towards, like, to understand a more, like, more in-depth thing, I guess, like, it doesn't really click.

I: OK, that was going to be the next question, "if this list doesn't cover everything you need to understand, what more is there?" I think you covered that...

S: Yeah. Definitely.

I: All right.

I reads question 3. (OR: disagree)

S: Um, that'd be another disagree, because, like, especially during homework, like, especially when doing it with other people, it helps out a lot, and like, we'll come up with something and be, like, "do we do it like this?" Even if we don't, even if we don't complete the whole problem and get something at the end...

I: Mmm-hmm...

S: Like, if I'm just doing a problem, and all of a sudden I come to, like, a point where, like, I don't understand what's going on, we definitely have to talk it out, or like, I definitely have to, like, reference the book, or if I have another question, I'll go to, like, the office hours, you know, and try to understand it a little bit better.

I: OK. OK, so that sounds like you described in the what your process of... what happens when you get stuck with something, right?

S: Right.

I: If you're stuck, you have to refer to the book, or you talk to your people when you're working in groups. Um, did you do a lot of your homework in groups, or by yourself?

S: It was usually in groups, like, sometimes, like, I would just look over on the Web site, and then see what I need to do and, like, maybe rights some little notes down for something, and print it out, but, to actually go through the mechanisms of, like, doing the homework, it was definitely the group.

I: OK. The issue that this question is specifically addressing is... supposing after you get free you're stuck points, and you come up with a way of calculating something, and at the end you have an answer, and then just look at an answer and... and it seems different from what you expect, do you trust that?

S: Do I trust... do I trust what's in the book?

I: No, the answer you got.

S: The answer that I got.

I: Right, I mean, if you do a calculation and it gives a result different from what you'd expect...

S: Do I trust that? No, probably not.

I: Right, OK, well, what do you do in that case then?

S: Then I go to run in go back... go back and do it and see what ever stopping points I had originally, go back and do it again, and see if there's, like, something that I might have messed up on because, because usually, if there's a problem between my answer and what I would expect...

I: Mmm-hmm...

S: I would definitely go back, but if I ended up getting the same answer again, I probably go ahead and just trust that... that intuition, you know, just, like, going back and check yourself.

I: So, do a check on the...

S: Yeah, do a check, and then if it still comes out with an answer I wasn't expecting, then I would probably go with that one. Like, if I would do double check on that.

I: Oh, OK. So doublechecking on a calculation would be what you do, and if it checks out...

S: Yeah... because I could have put something wrong into the calculator, or have a sign wrong, or something.

I: OK. So, the next problem, four.

I reads question 4. (OR: disagree)

S: Um... I guess it's more of a neutral kind of thing, like, it's... it's not the main point, but it is a main point, I guess... uh, to see where it's coming and make sure it's valid, I mean, because we always need that, at the same time, it'd be nice to see, like, applications of it and see, like, exactly... exactly what it means, like, instead of just being symbols and seeing that it's derived from another equation, or

something like that.
I: OK, OK. When you talk about applications, um, in what way does seeing where the formula comes from help with applications?
S: Like, for instance, a lot of, like, we're learning that a lot of, like, equations especially with centripetal force, like, momentum and stuff and seeing how it's applied to the main, Newton F=ma type of equation, and like, that'll give you like a better understanding of, like, it's not just to see that, like, where a formula comes from and then it's OK to use it, but also understand it at some point, at some level. And that would help your application a lot better, if you understand, like, how it's derived and what's the best place to apply it at, and like, those type of factors.
I: OK, all right. I think that covers most of it, so let's see the next one.
I reads question 5. (OR: agree)
S: Uh, that's probably agree.
I: OK.
S: Um, I mean, that kinda goes back to the question one, where, like, understanding situations in my everyday life, so, I mean, we did that in class a lot, like, using the touchstone experiences or whatever, and like...
I: OK.
S: To understand, to relate it to, like, parts of my everyday life.
I: OK, um, when something like this comes out, I'll let you know, because a lot of these questions seem repetitive to people, and if it seems that way, let me know that it seems that way, and then what I'll try to do is explain the differences in the wording, because there are subtle wording differences in between them, this first one, for example, asks whether you agree if learning physics will help you understand situations in your everyday life. The one I just asked, five, talks about when learning a new physics topic, it's important to think about personal experiences, so... one of the questions asks one way... how... does physics [understand situations...]
S: Yeah, yeah.
I: The other one, do everyday situations help you learn physics?
S: Right.
I: It's kinda the reverse.
S: Yeah, and that's what I'm saying, it's kinda parallel to each other in the fact that by doing physics, in number one, learning physics helps me understand situations in my everyday life, but also applying the situations in my everyday life can help me learn physics, it's like a give and take kind of thing.
I: Mmm-hmm.
S: And... it is important to just... to just put numbers and symbols up on the board, and so you learn this equation, and apply it to whenever you see this situation.
I: Mmm-hmm.
S: It doesn't help me personally to learn as much as applying it to real world... situations.
I: OK. Can you think of an example from either this semester or the last one where to learn a physics topic, you needed to conjure up some example [on] experience?
S: The whole... modeling aspect in the second semester, when we were learning about electricity...
I: Mmm-hmm.
S: And there was, all right, how can we use a model to explain, you know, what electricity is? I mean, we had the water model, but to get through that, what we'd always use was that battery/circuit... type of... that basic real world experience of seeing a battery in a circuit or a light bulb in a house, or something, and you understand that it glows. So, we knew that would have to be a major component in our model, and that's how we ended up applying it and helping us understand the physics itself... is by taking this real world example and making a model out of it, and then going on from there.
I: OK, so the instance where you're making circuits out of batteries and bulbs, this was in the lab, right?
S: Yeah.
I: That seemed like a real life experience to you, then, at that point, once you'd done it, right?
S: Yeah.
I: The reason I ask is that sometimes physics labs, even if they're dealing with household stuff, seem artificial to people, and I was just wondering to what extent that seemed authentic.

S: Well, I mean, it was obviously artificial, because it was in a lab situation, so you have to worry about that, but at the same time, I could easily apply it to saying... oh, when I switch on my light in my house, I understand it also goes in a similar circuit to this...

I: There's not that far a move from, from turning on your light switch?

S: Yeah, exactly.

I: All right, so let's see next...

I reads question 6. (OR: disagree)

S: Once again, it's a main point, but it's not *the* main point, like, the main thing that's needed. Obviously, there's a lot of math involved in physics, and if you don't understand how to use the formulas and how to apply them in certain situations, you're going to get lost eventually...

I: Mmm-hmm.

S: But at the same time, all of the stuff we've been talking about... using the real world examples and doing all the modeling and stuff like that, it helps... it helps, the conception kinda needs to be there before you can definitely use the formulas.

I: Mmm-hmm. OK, so that sounded like either a neutral or a disagree.

S: Yeah.

I: So, do you have a preference one way or the other?

S: Probably a neutral again, because it's a main point, but it's not *the* main point.

I: OK, all right. What's next? Seven...

I reads question 7. (OR: agree)

S: Um, I guess I disagree.

I: OK.

S: Because it's many pieces of information, but they're not all primarily in one specific piece, it's not like you can go... you can't go chapter one, chapter two, chapter three, and have it be totally individual things, we see that everything... there's a lot of... there's certain situations where, yeah, they're separate...

I: Mmm-hmm.

S: But , there's a lot of stuff, especially with the force and the movement, that we see that all things are kinda like... are interconnected with each other. You know? And even like... when we learned about how light is an electromagnetic wave, and we learned about electricity and magnetism beforehand, and then we understand from that... we were able to understand, how exactly like is made, because of the electric field and the magnetic field going back and forth between each other. So... you can't totally separate every little individual piece from each other.

I: That was kind of neat, wasn't it? I mean, when you heard about it. We did these things with charges, we did these things with magnets, and that doesn't seem like light, but…

S: Yeah, exactly.

I: There are aspects of those things in light.

S: That was definitely one of those "light bulb moments" in class, when I saw that, I was like, "Oh… that makes sense… electromagnetic spectrum, blah blah blah…"

I: A light bulb moment, I like that, all right… OK, number 8…

I reads question 8. (OR: neutral)

S: Um, yeah, I think I agree with that, I know I had to… I think it was the first exam

I: This semester?

S: This semester. I didn't do too well on it, but the very last question was about… magnetic fields and how to derive the question with the… what was it? It wasn't the capacitor, what was it? I forget what it was, but we had to…

I: It was a quarter circle shaped slab…

S: Yeah, yeah yeah yeah, and… I wasn't… I couldn't remember exactly the v cross B force for the equation, or whatever, so I kinda tried to derive something out of the force = ma equation, and I kinda got half credit for that because I didn't have the exact everything…

I: Mmm-hmm

S: But I definitely remember trying… definitely trying to eke out, if I had enough time, it probably would have finally clicked to me, but I can definitely get at least half credit for deriving… once again going back to the other equation, or the other question… things are definitely intertwined so that you can definitely come back to something by route of another, another example.

I: So you're saying you weren't… you weren't able to come up with the final one you needed,

[right, right] but it was a time pressure issue?
S: Yeah, yeah, cause it says… if I had enough time…
I: Given enough time.
S: Yeah, exactly.
I: That's one of the stipulations, so, fine. What's next?

I reads question 9. (OR: neutral)

S: I guess maybe a neutral, I can definitely see some people that… you could separate it, but at the same time, I have to disagree, somewhere between B and C… you can try to separate it, and look at it just from a certain angle, but me personally… to understand it, to totally comprehend it, I would need more of a real world application so… I know someone like I notice Prof. [PER prof] really likes the math side of a lot of the stuff, filling the math out. Since I'm not as… I'm not, like, totally good… I guess that's really bad English, but I'm not… I don't identify as much with the mathematics end of it, and you can definitely do a lot of this physics stuff… totally mathematics, and totally understand it from that side, but for someone like me, I don't think it's… a reality to think of it just in a non-real world sense… not applying it to…
I: Do you think that's just because you're less comfortable with the math?
S: Yeah, I mean, that's the only other way I could think of physics, it's either you relate it to the real world, and use a little bit of math, or you use a lot of math and don't really relate it to the real world. I guess you could just do… "this is how it works, don't think about it anyway…" but I can't… you couldn't talk about force without saying… if you have a block on the floor and you push it, as soon as you bring that kind of example, it's a real world application.
I: All right. OK, then, next one.

I reads question 10. (OR: disagree)

S: I disagree, because although it is a main component, to understand it fully, it goes back to that again… you definitely have to talk it… I would definitely have to talk it out with my homework group if I didn't understand something, and then try to apply it to either the real world or something that we learned in lecture, you know, and to just plug and chug and just put numbers into equations, sometimes that doesn't really work..
I: OK, notice here, you are allowed to use "facts or equations" and so "fact" may be something… you get from lecture [Right] if you copied off notes…
S: So if you're doing a problem solving…
I: So if you think about problem solving… [Right] does that mean to you… take a problem, match it with corresponding facts, wherever you got 'em, book, lecture, whatever, and equations, and substituting values to get a number…
S: Well, there are certain situations in class where it wasn't always… to get a number, where it was…
I: What was that like?
S: Well, I guess I was getting… I guess with the estimation problems, I guess you were ultimately getting a number, but I know in those situations it wasn't just… have an equation and put numbers in, because, you'd have to estimate something and bring something of your own experience into it, but I guess that can also be considered as facts. Where exactly does facts end and nonfacts begin?
I: You know, I don't know, estimating things… often you don't have exact facts, that's why we call it estimation.
S: Right, right, so I mean, I guess it depends on the problem solving question itself, I guess there are certain situations where, yeah, you can just put numbers in and try to get a number out. I'm pretty sure there are certain instances, but at the same time… I guess what I'm trying to say is, especially with the problem solving type of idea, you have to bring… a certain… a part of whatever your understanding is, you know what I mean, whatever part that you've come to understand about that given physics problem… through class and everything that you've learned, that you have to bring that certain… I don't know the word I'm looking for, you have to have a certain understanding (totally?) of an equation, and then plug in your facts and your equations, and then try to get a number out of it.
I: That certain *je ne sais quoi*.
S: Yeah, very good, (bringing out the?) French on that one…
I: I don't know what… as Dr. Evil might say. So, next one, before we bust out too many more foreign languages…

I reads question 11. (OR: disagree)
S: No, that's a strongly disagree, because… that's what we've been talking about the whole time… to totally… to apply… I guess it's also back to the number 10, to use my equations, there has to be that certain something that gives me the connections that I need, because, I mean, from just going from numbers and symbols… it can either just be numbers and symbols, or it can actually intuitively mean something to you… where I can understand it, like theta is an angle, or q is a charge, or something like that, you know?
I: Were there any equations you can think of that you did understand in an intuitive sense?
S: I guess go back to F=ma, a big one… 'cause we spent so much time on it [OK] just understanding exactly… you have to have the mass and the acceleration and… you're looking inside and seeing whatever applications you've done with that, where if you know the forces have to equal each other when… two cars crashing into each other.
I: On the flip side of that, were there any equations that seem like they didn't make sense at the time and had to be accepted as givens for a short time, temporarily?
S: Um, well, I guess you could almost say that every equation at the beginning is like that, 'cause we didn't have necessarily enough intuition or maybe vocabulary or nomenclature, to understand exactly what was going on, but eventually, usually almost everything clicked, I'm trying to think of anything that didn't, like, end up… I think the hardest was definitely the end of… when we started getting into the quantum physics stuff [Mmm-hmm]. That was definitely the hardest stuff to really, to really get down and understand exactly what was going on.
I: You didn't get that many equations, though, did you?
S: No, we didn't… I guess the photoelectric effect…
I: That counts.
S: Yeah, that was like the main thing, but I mean, even that, that was pretty easy to understand, just the fact that we're looking at photons bouncing into electrons, you know? So that, to an extent, I guess even that I eventually got reconciled if I didn't understand it at first.
I: Mmm-hmm, all right. OK, let's see this next one here, we got through most of 11…
I reads question 12. (OR: neutral)
S: Um, I think, I guess agree on that [OK] just from the standpoint of getting a right answer, you know?
I: Did you find yourself doing this?
S: Um, not as much, I'm trying to think of a situation where I might've had to equate two different approaches… [Right] I guess when dealing… like with the… the exam problem I was talking about with the force of the magnetic field, or whatever, how I went about it and tried to go about it in another way. [Mmm-hmm] Then again, it would eventually come full circle and I would eventually get what I was looking for initially, I guess, but I can't think of anything specifically where I might have had two different approaches. But I think I would have to agree with it just definitely because if you go at it two different ways and get two different answers, then you find out which one is more correct, you definitely have to go with that one. That approach.
I: OK, all right. Next one.
I reads question 13. (OR: disagree) Interjected: I: I guess you have your grade already, so…
S: Uh, disagree, because, I mean, all we do is the insight and creativity with the modeling, you know? Since we don't have… say I was familiar with the material on electricity, I understood the equations, and all that, but… [Mmm-hmm] it didn't really come full circle, it didn't reveal itself as an actual concept until we used the creativity of using the models, and being able to understand, supposedly, it flows like water, there's no definite thing you can call electricity you have to use those models, and you have to use creativity and insight to help, help the concept become fully realized.
I: And that helped with homework questions and other things that you were graded on?
S: Yeah, exactly.
I: You didn't get points for that modeling stuff.
S: Yeah, absolutely…
I: That would be my next question, then, if you didn't, then how was that so important? OK, but I think we covered that, so, let's go to the next one, I guess… unless there's anything else you haven't… if you have a thought forming in the back of your head that I interrupted…
S: No, nononono. You said exactly what I was thinkin'.
I: Last thing I want to do is put words in people's mouths, so…

[S chuckles]

I reads question 14. (OR: disagree)

S: Um, I guess disagree with that one, because, what was the… there was one in the first semester where, I guess it was the, with kinetic and potential energy, that was kind of a hard concept to get at first [Mmm-hmm] because… moving… what was it? You can have kinetic energy build up when your potential energy… when you raise something to a certain height, it has a certain potential energy [Mmm-hmm] and when you drop it, you're using, you have the kinetic energy going up the whole time as you drop it, and you can not only have kinetic energy going up and down, but you can have it going left or right, and there's something about… but you don't really have potential energy when you're moving something left to right, because you don't have that gravity force, I guess [OK], so those kind of… that was kind of hard to reconcile at first, to totally understand how you can have kinetic energy and not potential energy in the left to right movement, or whatever. I remember there being a discussion with my lab group, and we had a hard time, we spent a lot of time trying to eke that one out, to totally understand those concepts.

I: So, you knew it, but you didn't originally accept it at first?

S: Right, right, yeah. It was like, "wait a minute, don't I have to have potential energy to have kinetic energy when it moves…" and they're the inverse of each other, and all that other stuff, that was kind of hard to work this out.

I: You had thought there was sort of a tradeoff between the two [yeah] and here you found this case where it wasn't so much of a tradeoff, because potential energy wasn't changing at all?

S: Yeah, yeah, exactly.

I: All right. You must have had an interesting homework group.

S: Yeah. [chuckles]

I: Let's see what's next. 15.

I reads question 15. (OR: disagree)

S: Um, I guess neutral, it depends on the case. Uh… I mean, I guess practice makes perfect, so if I haven't seen something before, then it's gonna be hard to totally go at it, but it's not to say that I wouldn't… have much of a chance of being able to solve it. I definitely think I could probably come up… bring something else to the table that I might… I wouldn't totally forget it, and skip it, and go on to the next question, you know? You definitely have to go back and try to work with it and try to reason it out, and try to figure out… "what else do I know that I can apply to this and maybe, like, find some answer."

I: All right. OK, I have nothing else to add to that, so let's see what's next, 16.

I reads question 16. (OR: disagree)

I: So this is different from the other questions about experience, by asking… in cases like this, should you just focus on the book?

S: No, disagree.

I: OK.

S: Once again, if I… if and when I have a question with the textbook, if I don't understand something, I definitely have to reference it and check it again, and see if I can somehow reconcile it with my own experiences. I'm trying to think of… there's definitely something similar to that, where… at first, I can't remember, there's something… there was a big one last semester too, where at first it seemed to totally contradict what my initial experiences were…

I: This was something in the book?

S: Yeah, something in the book. I think it was also something he might have brought up in the lecture, it was definitely something in the book, I remember reading in the book, and then, we talked about it in lecture, and it became… it was more than just… there were a couple people that… I guess it was most of the class… it didn't seem to go… I can't remember exactly what it was. But yeah, if something… if at first you don't succeed, try, try again. So, if there's something in the book that just doesn't click at first, or doesn't seem to go with my own experiences, I'd definitely have to… read the book again, maybe ask somebody else what their opinion is, ask the T.A., ask Prof. [PER prof], and see how exactly this fits in with what I… 'cause if it's not… you can't have your own experience and then have it go… it doesn't seem like it'd be right to have an experience and have it go against what the actual physics of it is. There has to be some way that you can reconcile it to… so that they meet at some midpoint, say, "all right, this is why I see this, and this is how it [unintelligible] about physics.

I: OK, so that's a course of action you suggest to her in this case?

S:	Yeah, yeah yeah. Definitely, definitely just don't throw it out and say, "my personal experiences are wrong, I just need to learn physics," you know? The best way to learn physics would have to be to reconcile it with your personal experiences, to totally, fully, understand it, you know?
I:	OK. All right, so, next one then.
I reads question 17. (OR: disagree)
S:	Um… [long pause] I guess I'm between disagree and neutral, because, once again, the mathematics part is a big part of it, to use equations and understanding how to apply them, but to… when doing a physics problem, if I'm doing something in, say, a math or algebra class where you definitely just put the numbers in, you're dealing with these real world examples where you have to apply the equation that you have, you know? You can't just say, "oh, I have this equation and it works in this situation, I'll just put the numbers in, I have to understand… for me anyway, I have to understand why exactly that equation does belong in that situation, you know? To understand the… there are certain, once again using real world experiences or whatever you want to use, understanding the whole scope of the equation that's being used, is definitely an integral part of solving the problem itself. Otherwise, it's just not very [unintelligible].
I:	Hmm. OK, what did you take the phrase "finding the right equation to use" to mean?
S:	Uh, just, uh, OK. [long pause] So, I guess just applying the equation, I guess, to say, "oh, I'm doing a momentum problem, so I have to use a momentum equation, or something like that. And you have to… not only know when to use the equation but understand why you're using the equation.
I:	And doing those things is part of this "finding the right equation to use"?
S:	Uh, yeah, because, well, to find the right equation… I could just say, I could just look at something and be like, "OK, it's momentum, so I use p=mv or whatever." [Mmm-hmm] but, I could just, that would be easy, I could just look at a sheet and say, "momentum, p=mv, force, f=ma, blah blah blahblah," and just look at it like a cheat sheet and say, "all right, this is what equation I'm supposed to use." [Mmm-hmm]. But, let's say, for instance, that I don't have that luxury, you know? I don't have, I'm not exactly… I'm not… I don't have a cheat sheet, I guess, to use, and for finding the right equation, I have to understand what scenario I'm in, what factors I'm using if I'm using… if it's just mass and velocity, if there's an acceleration to use, or whatever, and be able to apply that in finding the right equation, you know? To understand it a lot better helps you find the equation better, I guess.
I:	All right, I think we can go on to the next one, there's no reason to dwell on these for five minutes each. 18, then.
I reads question 18. (OR: neutral)
S:	Um, I guess I would agree with that to an extent, that, I know just personally, what I think, I can come out of an exam and say I did pretty well, you know, I did this, I did that… but at the same time, when talking it out with other students, it can either reinforce or break down the conceptions that you had coming out of the exam. But I mean, when I come out of the exam, I'm usually like, "OK, I did pretty well on it," or "I did really bad on it" you know?
I:	And does it turn out that you're right?
S:	Yeah, yeah, generally, generally, yeah.
I:	It does? OK, I got a lot of interesting responses to this one, because there are some people that say they completely get it wrong every time… they think they failed and got a B, or something, they think they did well and bombed it.
S:	I mean, yeah, I mean… sometimes I might be… I can't… I never come out of an exam, you know, "I aced that" or, you know, "I totally failed it," but I can have a sense of why I didn't do too good on that one, and usually that's… usually ends up being what happens.
I:	OK. So let's see, next one, then.
I reads question 19. (OR: disagree)
S:	Uh, disagree… [OK] because, once again, I'm not too keen on just numbers, and equations, and symbols, and stuff, and… uh, to just say, just to have that cheat sheet again and say this is momentum, and this is the equation that you use… [Mmm-hmm] it doesn't help me out at all. And that's kinda like what I… I noticed a lot of stuff, maybe in high school, when I had a physics course in high school, it was just like, "OK, we're dealing with torque, if you ever see a guy standing on a scaffold, then you use this equation," you know? Like one of those things.
I:	Was it like that?
S:	Yeah, yeah.
I:	Hm. OK. My impression of what people consider "solving lots of problems" is different. It

seems to me, you said… someone is standing on a scaffold… use this equation. Um, do you consider that different from doing lots of example problems?

S: Well, but, it says… when you're… you're talking… you spend a lot of time on the concepts, so, like, instead of just saying, all right, here's an example, it's a guy on a scaffold, blah blah blah, we also have this point where we spend time on concepts, where we understand that it's torque, and we have this rotation and you have the perpendicular force, and we talk about… the proof of the equation and understanding that when you do have a guy on a scaffold, instead of plugging numbers in for… they give you the torque or the acceleration or whatever… you can say, "he's standing on the scaffold, and what's gonna happen is if he walks off here, it's gonna do this, if he stays in the middle it's gonna stay flat, you know? And to be able… if you spend time on the concepts, what exactly's going on, and the general… the proofs of the equation to apply it to something we've already seen, that helps in the overall ability to solve those equations to understand those concepts.

I: Hmm, all right. So, it sounded like you were giving me an example of a professor being qualitative. [Right, yeah] "instead of using this formula, we'll go through these cases, and talk about what happens first…"

S: Absolutely, absolutely.

I: OK, um, so let's see the next one then.

I reads question 20. (OR: neutral)

S: Uh, disagree. [OK] It definitely just wasn't memorization. Even when I'd have to recall, say, an equation or something [Mmm-hmm] when we're studying for an exam or doing homework, it was… the way that… it's almost like, the way the recall of the memory came up was by an open discussion, how those concepts were applied, you know? To just… I can spit out one of the equations, or something, but almost definitely either before or after coming up with that equation was a discussion of how was it applied. When we were studying, it was like, when we're talking about, when we're talking about gravitational field… I really didn't… I wasn't sure about the equation at first, and then we started talking about it in our study group when we were studying for the exam, and that's when the equation clicked for me. So… it was almost… once again, for the memory recall, it was almost shifted to… I had to have this open discussion, think in my head… how it's applied.

I: And then you remembered the discussion?

S: Yeah, and then I remembered what the equation was from that discussion.

I: Is it easier for you to remember discussions than equations?

S: I guess sometimes, it's almost like a Pavlovian response… by me talking about this, oh, that's right, the equation is G… M… whatever…

I: Did you all slobber when someone rang a bell next to you?

S: [chuckles] No.

I: Well, that's good, all right. What's next, then?

I reads question 21. (OR: neutral)

S: I disagree. I mean, that was definitely, there's definitely a big component of understanding physics with the real life examples and sample problems and all that [all right], but if I didn't have the homework outside of class, or I didn't have the discussions and the extra help, or whatever, then it probably wouldn't, it wouldn't have clicked as much. I know, for me personally, in first semester, I really didn't do the homework that much, and that kinda hurt my grade, that ended up hurting my… uh… not just because of not doing the homework, but even the exams or whatever weren't as up to par as, say, this year, or this last semester, where I actually did all the homeworks and it actually helped improve my grades, my exam grades, and other facets of the class.

I: Hmm. All right, then. Let's see.

I reads question 22. (OR: disagree)

S: Disagree. [OK] Back… that even goes back to, like, the very first question, how does physics explain everyday life… [Mmm-hmm]. Definitely it does apply to certain simple situations, but then again, I can, you know, walk down the street and see guys… in a moving van or whatever… moving furniture out, and I can understand not only does he have the normal forces of the couch bumping up against him, but he has that weight of gravity working against him too, and it just gives you a different scope, I guess, in the application of real life situations and experiences.

I: OK. This is a valid concern of ours because it is true that physicists like to simplify everything. [Yeah] This is one of the first things he always says in class: that we simplify things 'cause otherwise, the math gets horribly complicated. [Right, right] So for a lot of people, that disconnects them from the material, because so much is idealized [yeah] you do tons of projectile questions where there's no air resistance [right], lots of rolling problems where there's no friction [right], all sorts of stuff like that, so… so we get a variety of opinions, that's why we ask, I think, I don't know, I didn't write all these questions, but I'll be changing them later. 23.

I reads question 23. (OR: disagree)

S: I guess a neutral, because there's definitely situations where it helped for having someone… usually, almost in every situation there's at least one person that understands it relatively well [OK], and is able to explain it to other people. But there's a lot… there's also a few situations, I guess it wasn't a lot, but there's a few situations where neither one of us was exactly sure what was going on in a given situation, but each of us could piece something together from what we knew in ourselves… what we learned specifically, of ourselves. With, what was it… with the whole, um, when we first started learning about electromagnetism, and stuff like that, and understanding that it was the electric field and the magnetic field, and… I know, not all… at first, there were a lot of people that weren't exactly sure, and I think I had a concept… like a "light bulb moment" or whatever, but it wasn't fully realized, but when we had the discussion with somebody else, they would say something and it was like, "oh, so that's why this happens" and then I could be able to explain it to somebody else, and, you know, that discussion… it was beneficial if one person knew it already, but it was also beneficial if we had that discussion… if nobody was exactly sure what was going on.

I: Mmm-hmm. OK. So, we're almost done with these short ones, then there are the dialogue ones at the end, and a couple questions at the end don't take long at all. [OK.]

I reads question 24. (OR: disagree)

S: Um… I guess that's… I disagree/neutral, I guess. [Mmm-hmm] Um, obviously the big concepts were an integral part of the essay questions, and all, but even understanding the… the short answer questions on the exams (coughs) it wasn't just helpful to know an equation or understand the application… to fully (unintelligible) kinda just helped overall… it just helped in general to understand the big idea and apply it to see how it works in regular problem solving questions.

I: OK, next is another equations one. Again, if you think it's too similar to something else, let me know.

I reads question 25. (OR: disagree)

S: Um. [long pause] I disagree with the part that… understand physics, the equations are really the main thing…

I: OK, is there something about the statement you agree with?

S: Uh, the other material, it does help you to decide which equations to use in a situation, obviously, whatever we were talking about before, but, I mean, it's definitely not most… that's definitely… that's not its only application, understanding other stuff. There's some, I guess… it helps to understand the whole scope of the given situation, the… the other materials, it says… it helps to fully realize where the equations are going, and it does help you to decide which equations, but it also helps you understand those equations.

I: OK, I think I followed that. 26, then.

I reads question 26. (OR: disagree)

S: Um, I guess, for me, neutral/agree with that.

I: You're somewhere between neutral and agree?

S: Yeah, I… I really only… I really didn't go back too much over my homework when studying. [Mmm-hmm] It didn't… it didn't seem like it was big of a part… it was good to go back and maybe do a couple of the questions from the homework, but I don't know if… going back and seeing what I might have done wrong, or whatever… if that really helped. If I got it wrong, then I'd probably go back over it and do it again.

I: Did you use the online solutions a lot?

S: Not really. No, I don't know, I guess it just didn't really… dawn on me or anything, but it didn't really seem to be a hindrance at all to not go back and look at the homeworks to see what might have gone wrong, just to… use them again, to do 'em again.

I: All right, I have to flip now. [OK]

I flips the tape, begins new side on question 27.

I reads the dialogue in question 27. (OR: C)

S: So, I guess that would be C, that I agree equally with both of them. That was the situation I was talking about before where, it's almost like, it depends on the situation, how exactly our group would look at something, ‘cause there’s a lot of times where, there was one person that had the ideas, but even… even so, sometimes that person didn’t have it totally, you know? So that goes back to that other thing where our group is good… going and discussing with each other and… to help us understand whatever given situation we want to (consider?).

I: Mmm-hmm. All right, so let’s see this one between Tracy and Carissa.

I reads the dialogue in question 28. (OR: B)

S: I guess B, just ‘cause I don’t want to totally cross out Carissa. I agree with more with Tracy than I do with Carissa.

I: So, B says Carissa makes some good points, what part of what she said do you agree with?

S: Well, just the fact that, once again, not everything is interconnected (coughs) most of the material does seem to be intertwined, but say, for instance, let me think… when you’re talking, I guess, about light, for instance [Mmm-hmm], there are certain applications… obviously it does have to do a little with the force, and the, and the electric fields and the magnetic fields, but once you understand how the magnetic field and the electric field interact with each other to create the electromagnetic waves, once you get to that point, you almost treat it… light is almost a separate unit, you know what I mean? You don’t have to necessarily muddle it up with other stuff that you’ve already learned, once you get that concept, you could go ahead and do it itself. But then, when you look at electricity, it’s intertwined, because there’s obviously different models, and there’s a lot of stuff that you have to keep together, you know? So, there’s certain situations where they’re not necessarily interconnected, but for the most part, everything is… it seems like everything is basically interconnected.

I: Does that explain why you agree mostly with Tracy in this case?

S: Yeah.

I: All right. There seemed to be a lot to that, I think, I think that’s good… (a bit of overlapping pointless chatter) I’ll get it all down. Good stuff. All right. Next one.

I reads question 29. (OR: C)

I: So I’ll let you just look at those.

S: I remember having done this four times…

I: I’m sure you’ve done it four times.

S: I’ve probably put a different answer each time. Um, let me think.

I: I should check that.

S: Yeah. Um, ‘cause I’m still not exactly sure which one is the best. I think…

I: Yeah, which do you think, that’s what we’d like to know.

S: [long pause] I think… I’m gonna say… I guess D, where you compromise a little bit with A but mostly with B. It’s good, I mean, obviously it depends on how in depth the exam is gonna be [all right], but if you have a lot of time, it would probably be good to learn all of the relevant chapters… all of the stuff you need to go… and not necessarily go as much in depth, but with the main points, you need to go really in depth with them, you know? So it’s like… especially if there’s a trickle down effect where it’s like… if I go in depth with what exactly F=ma is, and what’s momentum and other stuff on the exam… [Mmm-hmm] but if I go in depth with the main idea and then study all the little stuff but not as much in depth [OK…] and hopefully I’ll be able to use that big hierarchical king type of F=ma formula to then hopefully help me apply to everything else.

I: Hmm. All right. I think I followed that. As long as there’s some big idea at the top…

S: Yeah, exactly, there usually seems to be a big idea, a big, main idea.

I: Were you able to use F=ma a lot on, say, momentum problems, or the “little things” you talk about?

S: Yeah… well… I think it was the second exam last year, there might’ve been something like that where… I just, it seemed like there was a lot of… you see that the big main concept was F=ma, and it was being able to apply it to different situations like throughout the rest of… the rest of the problems or whatever you might have been… especially with the centripetal force, or whatever, when we’re dealing with that, when we’re talking about the different symbols and the different applications of that, the circular motion.

I: OK, all right, where are we now?

I reads question 30. (OR: C)

S: I think that was D, it would help a little. That’s what we were talking about before, it seems that when talking, when doing the applying the equations, or whatever, trying to figure out which one goes with what, is almost like… it was just as easy for me to talk it out and try to figure out

whatever… what the certain equation might be, even if I didn't have it verbatim cut down (interrupted by I coughing) to memory, it's just the fact that to go back and try to talk it out and try to figure out exactly what the equation should be applied to the situation.
I: OK, OK, sounds like things you had said before. I'll see later exactly how similar they are, but… so, this question from a popular textbook…
I reads question 31. (OR: C)
S: I think it's… I think it's like C. They're fairly helpful and worth a fair amount of time. It might be actually a little bit more D, that they're helpful quite a lot, because once again, if you get to start thinking about "wait a minute… yeah, that kinda makes… kinda…" 'cause there's a lot of "that kinda makes sense" points in physics, where… maybe we couldn't, once again, going back and reconciling with what we've done before, what our personal experiences are, excuse me, how sometimes it didn't quite fit… that seems to be one of those same type of problems where it's like, "OK, that makes sense, so why do I know that's not true, because, you know, for whatever reason it does happen, and the horse is able to carry the cart, or whatever…" So, by doing these problems, it helps you to get thinking a lot more, and it … by this thinking about it, working it out, it stays better in your mind and you're able to apply something a lot more… better to that. So, you shouldn't devote all your time to these questions, but there should be at least a fair amount of time that you should work on those.
I reads the Roy and Theo conversation of question 32.
I: So, what are the advantages of working with Roy or Theo?
S: Both…
I: There's an advantage for each?
S: Yeah, definitely. With Roy, it's obvious that he knows his stuff, and he understands that… you need this equation, here's what the book says, this is what we should be learning about, this is what you need to apply it… but at the same time, with Theo, since he's questioning it, it's almost by that questioning, it kinda goes back and it's like, by questioning… that doesn't make sense, by questioning the fact that the horse pushes the car even though it shouldn't… it doesn't seem like that would work, doing that, it helps you, it helps with the application and the understanding of the physics principles, and hopefully, that'll help you apply it and know it better.
I: OK, so for the next one, could you pick which of those… what kind of person would be most helpful to work with?
Begin 33. (OR: C)
S: Well, since I work with both a Roy and a Theo, I'd have to say C, 50/50. That… [OK] it was definitely beneficial by having someone that knew everything in the book, that understood the applications and was able to recognize when to use them. At the same time, I was kind of more like a Theo, almost.
I: You personally?
S: Yeah.
I: I see.
S: Not totally, but I was definitely… I would always question… all right, that sounds right, but why? And that would help.
I: So you, in your experience, worked with both Roys and Theos.
S: Right, yeah, absolutely.
I: Or those archetypes, if you want. [Yeah] All right, so, let's see.
I reads question 34. (OR: B)
S: Um, [pause] I guess… I guess I agree more with Carmela, but Juanita makes some good points. I don't know, maybe it is as a result of being able to explain it… it is the recognition that you already know it, but it seems like, it's almost like in your head… you have the jumble, the overall concepts, and maybe they haven't been formed together, but as soon as I explain it to someone, or I'm able to explain it, and even when I am explaining it, there may be a question that pops up that… from somebody that I'm explaining it to. By explaining it, by being able to form it and put it into words, then that helps you understand it a lot better. But at the same time, if I'm able to explain it a lot better, it is… it does make you feel better that you really do understand it, you know? So it's… it's more so Carmela in the fact that form it together, that helps me understand…
I: It's helpful to do that?
S: Yeah, it's very helpful to do that, 'cause you're able to put everything together, but Juanita

has a point that by you saying it, by you putting it out, it gives you more confidence and understanding that you know it better.
I: All right, good then. This one is a free response.
I reads the free response question.
(they get stuck…) I: Has that happened to you?
S: Yeah, yeah, a lot.
I: Why do you think it works that way?
S: I think it might be… what we were just talking about, where you might have it, but until you're able to apply it, it doesn't really… it doesn't really form, you know? And, I don't… I have a nebulous concept of, OK, whatever physics principle we happen to learn that day, but then when you go to homework, and you try to do it, since maybe because you haven't exercised it it hasn't, you haven't practiced those given concepts, it really doesn't work, you know? You kinda get stuck, and you're just like… all right, I don't understand, I thought I knew this, but I don't, apparently, you know? So, it's almost like "practice makes perfect," where if I'm able to take those concepts that… you know, when coach tells me to bend your knees more when you're taking a jump shot, until you actually bend your knees more when you take the jump shot, it doesn't work, it doesn't get applied, doesn't actually help you out.
Background (35-39 ORs: B, A, E, C, C)
I: OK, so, as a professional basketball player… no… so, what year/major are you?
S: I'm a junior bio/zoology major.
I: So, is that a pre-vet course?
S: No, no, it's like… it's just… they don't know what else to call it, so they call it zoology.
I: Do you know what you want to do with that?
S: Not totally sure yet, absolutely.
I: Without going into specifics, do you think there's anything in this course you got out of it that will help you… in what your maybe profession will be?
S: Right, I… I'm guessing it has to, otherwise, why would there be a requisite to take this? I'm not exactly sure.
I: People wonder that often.
S: Yeah, yeah. I'm not exactly sure where it's gonna apply yet, but I have a feeling, especially learning a lot with… 'cause I'm kind of interested in… obviously zoology has a lot to do with physiology, stuff like that, I know for instance that a lot of brain activity is definitely electrical… electrochemical, stuff like that.
I: Did he talk about that a lot? Neurons…
S: He… yeah, he mentioned it, every once in a while, it'd be like, "you're taking the MCATs, or, if you're gonna be a doctor then you should know this" or whatever.
I: He likes neurons a lot.
S: Yeah.
I: So you had [PER prof] last semester?
S: Yeah.
I: OK, and this is required for your major?
S: Mmm-hmm.
I: All right, so other science courses… what was your overall experience like?
S: This course as compared…?
I: Well, no, overall experience in previous science courses, not including this one.
S: Um, I guess… neutral. Some of them were good, some of them were bad. Especially… I know the chemistry department here is kinda bland, from taking chem. courses.
I: You're not the first to complain of that. I don't know… it was a general opinion, but you didn't enjoy your chemistry classes as much?
S: Not so much, I know a lot of times where the professors are kind of research guys, so they really didn't want to be there teaching a gen chem. course or whatever…
I: Sure.
S: But at the same time, it's like… I know… the main difference I saw between this science course, this physics course, and my chem. course, is when going to labs in chemistry, often times, I just mix a bunch of chemicals together… nothing really clicks with what I'm learning in lecture. [OK] You know, that's the main difference, here we discuss what we're learning about and how to apply

some of what we're learning in lecture and doing on homework and stuff. But in a lot of the chem. courses, it's not that at all, it's just… go in here, you're gonna use this equation for your lab, just do it, and leave after three hours, so it really doesn't help, so for chem. it's pretty much negative. For a lot of my bio courses, they were pretty fun, just because that's my major.

I: Well, bio labs… I took a 100 level bio class that was required for my physics major, and we had this predator/prey thing, where we had various hunting implements, some of had spoons, some of us had forks, and the prey were various kinds of beans, and they were either sitting on a flat piece of paper or one of those ribbed Styrofoam things, and we saw how the environment and the kind of weapon you were using [right] made a big difference in the beans that bit the dust.

S: Right. There seems to be a lot of bio courses that like beans for some reason.

I: And we used corn… crossbred corn to look at it and verify the Punnett square using chi squared tests.

S: Nice.

Confidence

I: It was a long time ago, freshman year stuff, I can't believe I remembered it. So let's do these last two… I feel my ability to learn physics is… what do you think that is?

S: Ability to learn physics is…

I: Do you feel it's well above average in the class, well below, or in between.

S: I guess just about average in this class. [OK] I don't know, maybe better than average, I don't want to gloat or anything, I'm not exactly sure… I'm not… I definitely… the way the physics was taught to me definitely makes me feel more confident about learning it.

I: OK, OK, so what do you think about your ability to learn physics with respect to other subjects? A better ability to learn physics, or less?

S: It's probably about the same, but I guess it is somewhat greater cause of the way this was taught to me, talking to other people who had, say, [Professor] or something like that, where they were kinda frustrated. I knew people who had [PER prof] first semester, and then took [other professor] second semester [Uh-huh], and I know that they kinda complain a lot, because basically all [Professor] does is just put equations up on the board, and, you know, they kinda weren't too happy with that, so to speak.

I: Well, so, I take it they left because of some scheduling conflict, then? Did some of them actually leave?

S: I know one of 'em… I know one of 'em left because she really didn't like how this was taught. [Sure.] She didn't… it didn't appeal to her, or whatever. I know someone who left because of scheduling conflicts. But the general consensus that I've heard… this is from speaking to other people who've taken the other courses was that [Professor] was easy first semester, but he was hard second semester, and that [PER prof] was hard first semester and was easy second semester. And I think a lot of that has to do… I know with me specifically, coming in here first semester, it was hard to get used to the new style of teaching. And that was… trying to get your feet under you [right] and try to learn… and then second semester, you took him again, and it was easier because you already knew what to do.

I: So, were there any questions on this in particular you found, because of the wording or whatever reason, particularly hard to come up with a response for?

S: Yeah, I remember… there's a couple of them, I don't remember specifically, but in taking it, doing… doing the survey or whatever at the end of discussion, because some of them seem to repeat, like you said, some of them seem to repeat, like the ones with understanding situations in everyday life, or whatever. I remember just like taking the survey and saying… "ah, whatever, I'll put whatever I want to on there, I'll just put a C or a neutral or something like that." But, yeah… [pause] I don't know which ones specifically, but it does seem like a lot of them are just kinda like… I know that… one of these discussion ones… (looks it over) I remember first taking 'em, but I think it was one of these discussion ones, I didn't get it at first.

I: You mean, the first time you saw it?

S: Yeah, the first time I saw it, it was like… one of these discussions didn't… the discussion didn't click with me at first. I guess, since I've taken it so many times, I understand it better.

I: So it's hard to figure out which one that was?

S: I think it was the Carmela/Juanita one.

I: Oh, really?

S: I have that feeling, just because… at first when I read it, I thought they were saying the same exact thing. There's definitely… [pause] once again, I remember when I first took it, it was like, what is this? Now that I've taken it so many times, I understand it a lot better.
I: That's certainly good. I hope that when we give it for the first time to people at the beginning of next semester, we can make it so… so we get answers that are more straightforward and easy to come up with.
S: Right.
I: So that's why I asked, but if you can't remember, we don't have to press it too much. Do you think it was pretty easy, going through it… when taking the bubble sheets to answer the questions frankly?
S: On the bubble sheets, you mean?
I: Yeah, when you were doing the bubble sheet, say, if you were sitting in lab, was it easy to look through and answer honestly… give your opinion, or did you get an impression…
S: I guess I tried, I definitely tried to do that. I don't know, there's a certain level, especially at the end of the semester [uh-huh] when it's like the last lab, and you're just like, "I just want to get through this, I've already done this already this semester." [Sure.] So, you kinda just cut your way through it. [Right.] But I mean, overall, I guess it ends up getting… you end up getting the impression that yeah, I did answer these frankly, or whatever.
I: Yeah, OK. Was there a strong impression going through here that you look at it, and you say, "I clearly know what the professor wants to hear on this question"?
S: Um, yeah, there's a certain sense of that, like… I remember when… first taking this and not knowing [PER prof] at all… [Uh-huh] I think… that was a little more frank than taking it at the end of the semester, where it was like, "all right, he wants us to use our personal experiences, use our touchstone experiences," so when I'd answer one of the questions, all right, I'd sit there and agree with it.
I: So you thought it was easier before you got to know him, and before he…
S: Yeah, exactly, because I didn't have an impression of him, you know?
I: Oh, OK. I guess there's no way we can (unintelligible), we can't do that enough.
S: I think it's almost… I don't think it's necessarily a totally conscious thing, it's like… just like, oh, this is what I should… you know, cause whenever you take those opinion sheets, you know, that's usually what you feel like anyway, subconsciously, I guess.
I: One part of our job would be to make that effect smaller.
S: Right.
(discussion goes off topic)
End of tape

Molly's interview

Interview: "Molly" MPEX2 survey, done on 5.23.02 at 2 pm.

(tape starts, I and S discuss briefly the results of the final exam, and this conversation is omitted here.)
I: So, hopefully, this'll be the last time you need to see these questions (S. chuckles). So, let's just get started with the first one, I suppose.
I reads question 1. (OR (original response): agree)
I: What do you think of that?
S: I agree.
I: OK.
S: Um, I mean, for obvious reasons, you can't put something heavy above your head and expect it not to fall on you, but… um… I don't think it has as much of an impact on my everyday life as… I don't think I realize as much as it does… you know what I mean? I think we don't realize physics has as much to do… you take a lot for granted, you take for granted that you walk, and you stick to the earth, and you don't fly up in the air.
I: Why do you think that is?
S: I don't know, because it's something that we do. You don't think about the fact that oh,

gravity is holding me down, and normal force of earth on my feet, you know, all that stuff.
I: Maybe not.
S: I don't (both laugh).
I: I don't think I do either. But in any case, that's fine, all right. So, let's see, let's look at the second one here. Yeah, if you agree particularly strongly or disagree, just indicate that. Really, agree or disagree one way or the other is more important, but if you have… if you aren't so sure, then say that, if you're strongly sure you agree or disagree, then indicate that too. So, let's see, what's the next one?
I reads question 2. (OR: agree)
S: I agree, I don't strongly agree [OK], cause I do think you need to think about… I like the way he gives us examples from real life, like… [OK], um, I remember especially last semester when we were learning torque, the seesaw example… you have a heavy person on this side, and a light person on this side, where do they have to be for it to even… I like those real life examples. And I don't think you can just learn the concepts… learn formulas, stuff like that, and understand.
I: OK, OK, that's fine, that's a good example of something he did in class that helped you. That's partially covered in this problem, actually. The things you need to do to learn most of the basic ideas are just read the text, work most of the problems, and pay close attention in class. Do you think there's anything important that you need to do other than those things I listed?
S: No, not really.
I: No? OK, that's fine. We want your honest opinion on this, so, let's see, what's next?
I reads question 3. (OR: disagree)
S: No, I disagree.
I: OK, all right.
S: There's a lot of things that can go wrong in a calculation.
I: OK, so does this happen to you a lot?
S: Not a lot, but it's definitely happened to me before.
I: You got a result different from what you expected?
S: Mmm-hmm.
I: Can you think of an example of that?
S: Um (pause), well, is it OK if it's last semester?
I: Sure.
S: Well, I remember I was doing something about… remember when we did the earth and the moon and the gravitational pull… [Sure] and stuff like that? Well, I got something like ridiculously high… it was like 198 or something like that, and you knew it was supposed to be less than 9, 9.8… or whatever it is on Earth.
I: Oh, an acceleration, you mean?
S: Yeah, something like that, I don't remember. [OK] But I got a really high number and I knew it wasn't right, so I had to go back and redo it, so I couldn't just trust my calculator or myself that I put all the numbers in right.
I: So what's your main method of dealing with problems like this? If you come up with something, you get a number that seems ridiculous?
S: Um, well, make sure that you did it right, because a lot of the things we did on a calculator, make sure you calculated it right, and if not, make sure your formula's right, because a lot of times, it'll be like I forgot to square something or maybe forget to divide by two somewhere, something like that… make sure all your (garbled) is right, and if it is, then just rethink your whole method of approaching the problem, because if all your calculations are right, then maybe you just did the problem the wrong way.
I: OK, so you check for computational mistakes first [computational first] OK, I think I follow, all right. So, now speaking of equations some more, let's see this next one.
I reads question 4. (OR: agree)
I: Do you agree with that?
S: (long pause) Yeah, I like… I like how he does the derivations, and stuff [Mmm-hmm] I'm not really a math whiz, but I like to see where things come from, and it helps me understand why it's OK to use, like, if we started here, and you end up with this little equation, and it's… I like to know where the different values came from.
I: OK, what does he usually start with?

S: Something really basic [OK], and he just kinda works… how when we came up with the 1234 electron volt nanometers (*Ed. Note: this is an approximation of hc)* [Oh, sure, OK]. It's constant, and I understand that it's constant. I liked to know where that came from. It helped me to understand, well, this is where it came from, so this is what we're doing with it.

I: OK, is that what you… is that why you think he did those derivations in class?

S: I think so.

I: All right, OK. They provide a different function for different people, some people just copy down the stuff, others just don't write down anything at all and figure they'll just use it in an equation, or problems… so. So it's good to hear your perspective, I suppose, then. Let's see, this next one is 5.

I reads question 5. (OR: neutral)

S: I strongly agree with that.

I: Strongly agree with that.

S: I mean, it's the same thing, when he uses examples like the teeter-totter, the seesaw, whatever…, I understand how a seesaw works, I understand how a door works, like, if you pushed inside, right near the hinges, it's not gonna open, opposed to if you push near the handle and stuff like that, and I know how a cell works, so I understand… like a nerve [A biological cell?] yeah, a biological cell, the propagation of current through a cell…

I: Through nerves?

S: Through nerves, yeah, like that. From knowing that, it helped me understand when he was talking about it in class. I like real life examples.

I: When talking about what? Was he talking about actual nerves or was this something related to the electricity unit in general that the nerve stuff was helping you with?

S: Yeah. I don't really remember, exactly, but I remember him talking about nerves, I was like, oh, I learned that last semester. So I guess… I don't know.

I: Well, at least you had some experience with it.

S: Yeah.

I: OK, OK. That's all part of talking about… thinking about your personal experiences and relate it to something he's trying to teach you. All right, so, let's see what's next.

I reads question 6. (OR: agree)

S: I'm kinda neutral on that one. [OK.] Like…

I: So, neutral because… you don't care one way or the other or you have arguments for both sides?

S: Arguments on both sides.

I: Can you elaborate?

S: You need formulas to do problems, you can't figure out a problem without using a formula, and you have to know which formula to use. [Mmm-hmm] But it, you need to be able to figure out which formula to use, and from that… I think you use… you need to figure out how to solve the problem, and from doing that, I think that's where life experiences and your personal experiences come in. Cause you gotta be able to… OK, if you have a formula, you can work the problem, but you're gonna have no idea of whether it's right or whether it's wrong… or, you know… you're not gonna have any sense of where you are with the problem, and that's why I think like… me knowing that… having all of this acceleration, having a 120 m/s… whatever… acceleration… isn't right, because it should be less than 9.8, I just have to know that. I don't know. I don't know if I explained it right.

I: No, I think so, I think so… you were trying to bring up the idea of experience again, past experience, I think. [Yeah.] If…

S: Formulas are important but you have to know how to use them, too. Like how to use them correctly.

I: OK, OK, this is one of the things that's indicated in the statement of the question, though. Adept use of formulas… asking whether that's really the important thing in solving these problems, and so far, I mean, you did mention the past life experiences, and that's certainly part of it.

S: That would show the *adept* use of formulas.

I: Ah, OK, so you use life experience as a prerequisite for being adept at using the formulas in the first place. [Yeah] OK, I think I understand what you're saying there. Right. OK, so this next one's not about formulas per se.

I reads question 7. (OR: neutral)

I: Do you agree with that?
S: I don't really understand the question, but I think I put neutral for…
I: I'm not asking you to remember…
S: I mean, I remember that I didn't… that question really didn't make a lot of sense to me in the first place.
I: All right, that's part of the reason we do in person interviews with stuff like this… so you have time to think about and explain whatever you want, and then we see what kind of things… you put them on the bubble… to see if they match, and if we need to clarify the question… then…
S: Could you do that? Cause I don't really know.
I: Then we'll have to think about that for future editions, but what this statement is saying is that it's asking if you agree with the statement that physics knowledge consists of pieces of information, little ones, you have your… you have the stuff you know about charge, and the stuff you know about velocity and the stuff you know about magnets, and they each apply to specific situations individually in pieces.
S: Yeah. I agree, but… there's also the big picture, I guess.
I: What?
(long pause)
S: I don't really know. You have this whole world, and it has all these different parts to it, and you can figure out each little part… like magnets, and stuff like that, but they all kind of have an effect on each other, isn't it?
I: I'm not here to tell you what the system of knowledge we have is like, I'm just interested in how you perceive physics as you've gone through it. Which message has become more clear to you, that you have these units, or it really exists in one sorta whole?
S: For me it was one kind of whole thing.
I: OK.
S: You can break it down into smaller pieces like magnets, and charge, and velocity, but it all ends up being a big intertwined thing.
I: OK. That's a fair observation, we're interested in hearing about stuff like that. I want to know where people aren't sure where to react to questions… (off task) So let's see the next one.
I reads question 8. (OR: neutral)
S: Um, yeah, I agree, because, again, he shows us the different derivations on the board, and he shows us… if you start with this one thing, you can get to all different things, there's a lot of different ways to get there, so…
I: Are you confident in your ability to do that sort of thing? Has this ever happened to you, to forget an equation and you were able to figure it out in time for a test?
S: Yeah, yeah. I don't know how I did it. But it was a…
I: Which one was it?
S: I think it was a power one, it was on the midterm, it was like… how much power do you need in your house or something like that [OK], and I couldn't remember exactly what power was, but I knew… I think it was… I knew current, and from that, I could figure out, I could solve for power or something, I don't remember exactly what it was… but, I don't know… I don't know if I'd trust myself enough to be able to figure it out, but…
I: But you think there's a chance you could do it?
S: Yeah.
I: OK, all right. I think that's really… see… I could *probably* figure out an ethical way, I mean, we're not asking you to be definitely sure that… you know you can find it, so… this next one.
I reads question 9. (OR: neutral)
S: Um, I'm kinda neutral, I guess on that one right now because for me it helped personally to think about the things that I see and how wavelength and energy affect each other, and stuff. It helps me to think about things that way, because it helps me remember… [Mmm-hmm] but I think physics is a… particularly physics 121 and 122… are exact sciences enough that they can be plug and chug, you can remember formulas and spit them out on tests without having to apply it to anything in the real world.
I: So that's a strategy for being able to solve problems and do well on tests, OK? There is a distinction in the question between understanding physics and getting questions right. Do you see a difference in that or not?

S: Between understanding physics and getting physics right?
I: To be able to get physics questions right by memorizing the formulas and plugging and chugging and getting the right answer.
S: Well, I guess we don't necessarily understand the physics.
I: Could you, though? Could you potentially do it without linking…
S: I think so.
I: OK.
S: Some people can. [OK.] I don't know if I'm one of them, but I think some people would be able to.
I: OK, sure, so, what's next?
I reads question 10. (OR: neutral)
I: Do you think that's an accurate statement?
S: Mmm-hmm. Yeah. (long pause)
I: Trying to think if I can come up with an elaboration on that, but I don't know if I can. So, that's what you picture, right, if someone asks you to solve a physics problem…
S: Mmm-hmm… you figure out what you need to do and you put in all the values that you have and figure it out.
I: All right. (off task – discussing the length of the interview) So, what do you think of this?
I reads question 11. (OR: neutral)
I: So, what's your reaction to that statement?
S: Mmm… (long pause) I kinda disagree. [OK] I don't think… this is just me personally, I'm sure some people just write everything down and can know it, but I have to… I wanna understand it, and kind of have a sense of where it's coming from, so I guess that's the intuitive sense… I don't like taking things as givens, I want to know why, and I want to know how, and where it came from.
I: OK, for example, when he told you about the equation the velocity of a wave is equal to the frequency times wavelength, something like that… did he show where that came from? There are a bunch of equations… your final exam question had something about this too, to discuss an equation and whether it's fundamental, or we derived it from something else. Now, the ones we derived from something else… he was able to start with something basic, and go through a bunch of steps, and get it. But there were a bunch of equations like F=ma, for example, or Coulombs law, or… there are ways of deriving this one, but I don't think he did it for you, v = frequency times lambda or c = f lambda for light waves. [Mmm-hmm]. Those aren't derived for you. Do you think you're able to understand equations like that in an intuitive sense?
S: Mmm-hmm. Well, I mean, you just have to think about them. I… once I kinda sat and thought about it I could understand why waves of a higher frequency or lower… wait, which one is it? Higher frequency has a lower wavelength, so there… they have different energy than a low frequency, high wavelength…
I: OK, yeah. Those were all correct statements, you didn't get them mixed up. I realize it's after the final, I've done this before too, where after a test I forget lots of stuff. All right, so that's what I wanted to address, because there's all these equations out there that weren't derived for you step by step in class.
S: Yeah, but I feel that I kinda have an intuitive understanding of why it is.
I: And you think you can come to that understanding most of the time?
S: Uh-huh.
I: OK, all right, so, what's next? Let's see.
I reads question 12. (OR: agree)
S: No, I disagree. I have to have all the answers. Most people what?
I: Most of the time, when you did questions in class, you didn't have the answer in front of you, but suppose you did, I guess. So, you were saying you disagree, why?
S: I want to know why the wrong one was wrong. If I had two different approaches, and I felt they were both right [Mmm-hmm], and it turns out that only one of them was right, I want to know why this one was wrong so I wouldn't even consider it as an option in the future.
I: You'd never consider it as an option in the future… you mean, on the same problem?
S: Right, on the same problem.
I: You would never use it…
S: I would want to know why I couldn't… why that problem or why that equation shouldn't be

used rather than the one that should be used.
I: OK, I think I follow that, let's see what's next. I guess this question is spoiled since you've seen your grade, but, let's see…
I reads question 13. (OR: agree)
I: So, do you agree or disagree with that?
S: I'm kinda neutral because, yeah, your grade depends on what you know and what you don't know, but… we also, we have the estimation problem, and we have the essay question [Mmm-hmm], so you have to be able to think about different things and be creative and have insight into the different things we've done this semester to understand and be able to write a coherent essay about why things are the way they are.
I: Hmm. OK, so.
S: The tests that he gives aren't… they're not plug and chug, you can't just remember equations and expect to pass.
I: OK. So his tests require [yeah] insight and creativity, OK. So, just out of curiosity, did you expect that coming in?
S: First semester? No.
I: Yeah, in the first semester you expected a more plug and chug course?
S: Uh-huh. I was looking forward to it.
I: Really?
S: Uh-huh.
I: How'd the first test go for you?
S: First semester? It went pretty well, actually… but I kinda expected it too from his homework, and his lectures, and he told us the format of the tests, but… I don't know, I kinda woulda liked…
I: I'm interested in what people think when they start to get the impression of the first couple weeks, that this isn't…
S: The first, the first semester when I came into this class, I expected to be told formulas [Mmm-hmm], and know them, and be able to figure out problems from them. I never ever expected this theory stuff.
I: I think the theory stuff is pretty standard, actually, even ones that just give you equations, it's all just presenting the theory. But… but this class…
S: This class is *not* what I expected physics to be at all.
I: Did you have it before in high school?
S: No… mmm-mmm. [OK.] I mean, maybe that was part of my problem, I had never taken a physics class in my life.
I: No, that's fine, I mean, a substantial fraction of people in our class had never had it, other people in the class have probably had it with calculus before, so I mean…
S: Oh, I probably had calculus, I just didn't realize… I took calculus, though.
I: No, they teach physics courses that use calculus as the main mathematics in it.
S: Oh, OK.
(off task – discussion of calc stuff)
I reads question 14. (OR: disagree)
S: No, I disagree. Strongly disagree.
I: OK.
S: Stuff has to make sense or else it can't be right. I mean, you can't just have something that doesn't make sense and expect it to be totally right, it had to come from somewhere, somebody had to think it up…
I: Sure. Do you think you can have something that's correct, yet sort of runs contrary to your intuition?
S: Oh, well, yeah. The whole force mass acceleration… the Newton… a truck hitting a car has the same force as the car being smashed on the truck, you know what I mean, [OK] that totally runs contrary. But you have to think about it, and then… then understand that their accelerations are different and their masses are different, so they have to make up for each other so their forces are the same. Once you figure that out, it's fine. It makes sense, you just have to find a way to think about it so it's right.

I: OK, OK, that sounds fair, I remember that. That's an example that sticks out for a lot of students, you break out the force probes, you smash them together, and they see the graphs and say 'these things must be broken'.

S: Yeah.

I: I don't know if you said anything like that back when you did it.

S: I think we did.

I: But I don't know.

S: We were really surprised.

I: Right. It's those kind of things that make life cool, I think. Good, OK, I'm glad you were able to elaborate on how you made sense of that. So, next one.

I reads question 15. (OR: neutral)

S: Um, I disagree, if I had enough time, I think I could probably think about it enough to find an approach where I could at least write something down. It might not be something we've done on homework, or something, the exact example he's given in class, but it has a lot of aspects of the same kind of thing. So you just need to kind of break it down and figure out what you need to do to solve it. Find… see what you have, and try to figure out what you're trying to find, and see if you know a way to get there.

I: Hmm. All right. So that one is related to the question on the previous page, only the one on the previous page said that your goal there was to come up with an equation you couldn't remember. This one is to solve a problem in general that you couldn't remember. So I think they're distinct questions, and you distinguished your responses to them well enough, I think. All right, so, let's see…

I reads question 16. (OR: disagree)

S: No, I disagree, you know why.

I: These all seem to be similar to one another, don't they?

S: Yeah.

I: I guess we've talked about the experience issue enough before. I guess when I'm going through these, if there's anything to me that I notice that is a difference between this question, and one you've seen already, I'll try to point that out. If you think… if you think something I ask is very similar to something I've already asked you, then let me know, I'll look at them both and see if I can tell the difference.

S: It's the same thing as the other question… to understand, well, maybe not. Well, I guess cause that one's asking if it disagrees with your personal experience, you should go with what the book says, and the other question is… to understand, you just have to read the book and do the problems.

I: Right, right, OK. So, how much did you read the book?

S: I didn't read the book.

I: Oh, you didn't? OK, so I was gonna ask for your experience on this issue: if you've ever read the book, and it said something that conflicted with your experience.

S: I don't know, personally… I don't know. For me, I bought the books last semester, I bought his books [OK]. They were useless. I hated them. I tried to read 'em, I didn't understand them. They were boring. I fell asleep numerous times trying to read that book. I don't know… [OK] You know. It's for research! Research! [No, it's fine.] I hated his books. They were boring as hell.

I: I don't even know if he'll read this, I'm only gonna probably be typing down just the responses to the questions, this book conversation was a bit off the task, it just explains why you didn't use it so much.

Question 17 (OR: neutral)

I: Do you think that's right?

S: Yeah, I do.

I: OK.

S: At the same time, you gotta figure, there are a lot of things that go into finding that right equation, but ultimately, it will come down to… you're solving a problem, you're trying to get a number, you need to have the right equation. Ultimately it all comes to whether or not you found that or not.

I: In the end, yeah, OK. I'll admit, I have trouble asking elaboration questions where you just say 'yes' to something like this, cause if you were to say 'I disagree with this', then I could say, 'Oh, what *do* you think is the most crucial thing?' but if you agree with this, so what you said was fine, so that's why I get stuck after you say something like this… hmmm… I can't really refute that, can I? [S. chuckles] All right, so number 18, next one, let's see.

I reads question 18. (OR: disagree)

S: Uh-uh. I disagree.

I: What's been your experience?

S: I did this problem on the midterm, and I thought I did it totally right, I thought it was all right, and I kicked ass on it, no! It was soooo wrong.

I: Which one?

S: I think I asked… it was the current one or whatever, and you had to figure out the IR…

I: The constant current source?

S: Yeah, I did something crazy, like… I don't even remember exactly what I did, but it screwed me up… something in it screwed me up, it was the asking of the question, and I thought about it wrong. I gave a different answer than what the question was asking, is what it boiled down to, and I thought it was totally right, kicked ass, it was a great answer, I was gonna get all my points. None at all. So wrong. Then again, there have been other times where I totally bullshitted answers, it was… pulled something out of my ass, and it was, whatever… and I got enough points for it that I was amazed.

I: OK, so in both of those cases, either you did much worse than you thought or you did better than you thought given what you wrote. OK. So you don't think there's really any way you can predict your score on a test, you just have to kinda wait until it comes back and hope for the best?

S: I think, I mean, you can have maybe a pass or fail, but I couldn't distinguish whether I got an A, B, or C.

I: Yeah, I don't think pass or fail is what we mean.

S: No, I couldn't tell you whether I got an A, B, or C on the test.

I: OK, OK, so let's see what's next here.

I reads question 19. (OR: neutral)

I: This is a question about the approach the professor should take to help you understand it, do you agree with that statement?

S: I don't know, I guess I'm neutral, because I think it's really good to go in depth with a couple of the concepts, and stuff, and that way we can kinda figure out how to solve different types of problems ourselves, especially if we have a really good understanding of the concept that we're doing [Mmm-hmm], but at the same time, it really helps to go over different kinds of problems, like, if you're solving for different things but you have the same equation. If you have… Coulomb's Law that has six different variables [Mmm-hmm], you're given four or five of them and you need to solve for one, I think it would help to figure out… OK if you're given… if you're trying to find this, then you can do it this way, but if you're trying to find this, you can do it this way, and if you're trying to find this, then you can do it this way then. I think that doing the different problems is also helpful.

I: So what you described sounds like multiple variations of the same kind of thing, where you're just given a different unk,own.

S: Yeah, but even… that's the only example I can think of. If you have… if you can have a concept that has… different problems…

I: That's fine, if you can't think of specific instances… I mean, I'm asking you all these, and you don't know what I'm going to ask you, really, so I can't really expect perfect examples every time, but just if you have one, I have to check once in a while. Right, so let's see, what was I going to say, we didn't mean for a discussion of this item the way we just did… what we should do, lots rather than a few… to be an evaluation of the current course.

S: Yeah.

I: You've hopefully had your chance on the computerized evaluations to send in a bunch of comments about the book, the class, prof, the TA, whatever. These question responses are what we're interested in. Next one, let's see, 20.

I reads question 20. (OR: disagree)

I: So do you agree with that, was that a problem.

S: Mmm-mmm. I don't think so. There was kind of a lot to know, but we had a semester to learn it, and in comparison to a lot of other classes that people take like history, like… even my biology classes and my chemistry classes… the amount of things we need to memorize was extremely small.

I: Compared to those other classes?
S: Yeah.
I: So there was a lot to memorize in this class, but compared to other classes…
S: It was nothin'
I: Really?
S: Yeah.
I: Hm. OK…
S: Because… there were certain… yeah, you needed to know that E=mc squared, but in this class, it was more knowing what to do with that than knowing the equation itself.
I: OK, OK. I've never taken organic chemistry, for example, but I hear that's pretty memorization…
S: bitch
I: Memorization intensive was the word I would have picked, but well…whatever floats your boat, right? All right, so let's see.
I reads question 21. (OR: neutral)
S: I agree.
I: You agree with that? OK. This is not meant to be a class evaluation, but do you think the 121 class did that for you personally, or did you find you had to spend a lot of time thinking outside of class?
(long pause)
S: Um, um… I did, I think, just because we had a lot of problems and stuff to do, and they were the homeworks and stuff…
I: Mmm-hmm.
S: But if I understood something in lecture, then I understood it, and I didn't really need to spend a lot of time studying the concept on my own.
I: OK, OK, that's fine. Let's see what's next.
I reads question 22. (OR: disagree)
S: No, I disagree [OK]. (pause) Physics… is the world. I don't mean to do the whole philosophical thing.
I: That's fine.
S: I mean, you gotta drive your car, and you gotta know how to stop, and you gotta know if you're going 70 miles an hour, you're not gonna stop 3 feet in front of the car in front of you, you've gotta break a little earlier than that…
I: OK, OK, what this question partially tries to address is the fact that when we do problems, we draw idealized pictures of everything: straight lines, boxes on perfect ramps… we eliminate friction a lot of the time, so does this really relate? We have to simplify or else we can't solve it.
S: Right, but I still think it does relate.
I: OK.
S: Even if you get rid of friction and stuff like that, if you're doing something in real life, you can still… I think you'll still be able to figure it out.
I: Mmm-hmm.
S: Like if you're trying to move a box… I don't know… I think you can kinda take that into account, you don't need exact numbers and stuff like that, but you'll be able to figure it out well enough.
I: OK. And most of the time when we talk about boxes, we don't get rid of the friction, we just leave it there and make you solve it. [Right] That's our job, though. We'd kinda be shortchanging you if we didn't make you do stuff like that. All right…
I reads question 23. (OR: neutral)
S: I agree with that, actually.
I: OK.
S: Yeah, I don't think… I think it wastes a lot of time if nobody knows what they're talking about, if no one has a clue.
I: Really?
S: And you need to figure it all out by yourself.
I: OK.

S: I mean, I guess eventually, you can come to a conclusion, but I just think it's a big waste of time.
I: What is, working in a group if…
S: No, working in a group if nobody knows what's going on.
I: OK, what was your experience, I mean, it was a long time ago, I don't really remember the group you were in when you were with me, but what was your experience like in the groups first semester and second semester?
S: Well, I was with Michelle and Miguel, I don't know if you remember…
I: Oh sure, OK, I remember them now.
S: I usually was with a group that knew what was going on, first semester, we all kinda knew [OK] at least something, maybe we all knew different parts but we were able to put it all together [Cool]. This semester, when we were doing the radioactivity thing, the one before the lab when we were trying to understand radioactivity… the one with the M+Ms and stuff like that. [Sure.] I just found it really frustrating because we couldn't really figure it out. We were talking, we were trying to find the general equation, and we had no idea what was going on, we were just so confused that… we just got so frustrated and we started being short with each other, and it wasn't a good atmosphere. It wasn't a good learning atmosphere at all.
I: OK, if you'll excuse me for just a second, I have to… [yeah, no problem]

End side 1

Begin side 2

I reads question 24. (OR: neutral)

I: What do you think of that?
S: Um, I think understanding the big ideas is helpful in regular physics problems.
I: Hm. OK, OK, so here's a distinction between this question and a past question, or the connection anyway. You talked about before that understanding the method for addressing each type of question is important… maybe more important than actually knowing the specific little equation.
S: Mmm-hmm.
I: Now we take that thing and… we say here… the key thing… knowing the methods for addressing each particular kind of question might be important, OK… Is understanding the big ideas then important for being able to do that?
S: Yeah.
I: So that results in the same answer, I guess, so maybe there wasn't really any confusion. I'm not sure, but, I don't know, that's one of the longer problem statements. Let's do the next one.

I reads question 25. (OR: neutral)

(long pause)
S: Yeah, I guess I agree, ultimately it comes down to using the right equation… you need everything else there to be able to figure out which equation you're gonna use.
I: OK. So, yes, the emphasis I guess here is on the last part… I'm not sure… the other material is mostly to help you decide which equation to use in a particular situation.
S: Mmm-hmm.
I: So, all right, next one.

I reads question 26. (OR: strongly disagree)

S: No, I disagree, cause I wanna know how I did it wrong, because I might not remember what exactly I did, just if I only knew I got it wrong… I want to be able to know how I got it wrong and why I got it wrong so I can think about… OK, this question's on the test or something… how am I gonna do it then? You know?
I: OK. OK, so let's see here. (Discussion of new rules. The questions are no longer agree-disagree.)

Begin discussion of question 27. (OR: C)

I: So… which of those five choices do you like best?
S: Hmm. I think I'm gonna agree… B… B or C. (long pause) I'm actually gonna go with B. I know it kinda disagrees with what I said before about having one person, but I don't think having one person know the answer so you can get out early and get the right answer's important, but I think it's important to be able to have at least someone to… at least different people that know different parts of the thing so you can string it all together and figure it out. Meena makes a good point, it's good because you listen to each other and hear each other's ideas and find out what's best, I hate being

confused all the time and not knowing if I have the right answer, that was a big thing with me in this class.
I: I noticed times where things in the class frustrated you, I wasn't sure exactly what it was, maybe it was just that working in group, you were just not sure in the end… um…
Begin 28. (OR: B)
S: I agree mostly with Tracy, but Carissa makes some good points (B). [Mmm-hmm]. I like the big picture, and seeing how things relate, and a lot of times they're all very different subjects [OK], but I think it's important to be able to put together how they do apply to each other and how they do relate.
I: OK. What about what Carissa said did you like… the second statement?
S: That different topics don't always have that much to do with each other, cause, I mean, they don't, so I think it's important to teach them as separate units, but once you understand them as separate [Mmm-hmm], it's important to put them together and show the big picture as how they relate to each other.
I: So, what's the advantage of keeping them separate?
S: I think it's easier to learn them [OK] cause you can focus on that one particular thing.
I: Oh, OK, OK.
S: And then kinda step back and see it all.
I: That was gonna be my next question… why is that, but you answered it before I asked, so, cool. Read the interviewer's mind, it's a good strategy. It works in job interviews too.
Start 29. (OR: E)
I: See which of those five you like.
S: Um, let's see, compromising between learning a few basic formulas in depth and learning all the formulas, but mostly toward learning them in depth, because [OK] I think if you know a formula in depth, you can, uh… compromise and change it around in a few different ways enough that you can be able to solve a lot of types of different problems with it. Be able to change it around.
I: All right, OK, let's see this next one.
Begin 30. (OR: B)
I reads question 30.
I: So, how helpful do you think that would be?
S: I think it would help a lot. Either a lot or a fair amount. If you can remember everything you read, well, that's great, you know? At the same time, I don't think it would be the most helpful thing because you still have to understand where things come from.
I: All right, all right.
Begin 31. (OR: C)
I: What the question asks is, if you're studying for a test, if you see a question like this, what's your attitude towards it? Do you think that's helpful, or not?
(pause)
S: I think saying this kind of question is extremely worthwhile, D or E, it's worth a lot of the time studying, because it includes so many different things like… all of Newton's Laws, and it helps you be able to apply it to a lot of different situations, so if you can figure out how to think about… Newton's Law in that respect, in that situation, I think you could apply that knowledge to a million different situations no matter what situation he gives you… if he gives you a car and a bus or a horse and a wagon, it's all basically the same.
I: So, were you able to use questions like this? You said you didn't use the book a whole lot, so…
S: Well, a lot of these were like homework questions… compare the three different models that we have… waves…the light, the ray, and the photon model. By having to compare and contrast them, it helped me understand them a lot better, by having to sit down and write what I knew about them.
I: Hm. All right. So, here's the argument between Roy and Theo…
Begin 32.
I: So, what we want to do first is say what are the advantages, if you can think of any, of working with each person.
S: Well Roy, the one looking out of the book, I mean, he knows his stuff, his formulas, and he can say well, this is what we're looking for, so this should be an equation we need. But, the other guy is kinda more in a way like me… if it doesn't make sense, you gotta know why… if there's something that disagrees with his thinking, he's gotta figure out a way to think about it so it'll all agree

eventually. He's gotta figure out why… if the particle's velocity is constant, how can it be accelerating? He's gotta find a way to… what is that exactly [PER prof] says? Refine his thinking, or something like that.

I: Refine his intuition?

S: Yeah, so it'll make sense to him.

I: OK, so…

Begin 33. (OR: C)

I: Do you have a preference over which…

S: Nah.

I: Type of person? 50/50? Really?

S: I would want to work with both. I'm usually the one asking questions, cause I don't understand, or something doesn't make sense to me, so I want things explained to me [mm-hmm] but at the same time, I need somebody there that can explain it to me.

I: Oh, OK. So, in terms of helpfulness, there's no distinction between the two, you think?

S: They'd be pretty equally helpful.

I: OK, good, then.

Begin 34. (OR: B)

I: Which of those do you agree with?

S: Mostly with the first one…

I: Carmela? OK.

S: I think explaining something to someone helps me understand it better. I mean, yes, it shows that I do understand it, but being able to articulate something helps… I think it helps you understand, because then you can come up with questions that you might have or conflicts in your thinking that you might have, also. Like, if you say something… "wait, that doesn't make sense, so it conflicts with this?" How do we think about that? You know?

I: OK.

S: Being able to explain something to someone else is the same thing as me explaining it to myself and putting it in my head again, OK, this is… this is what it is, this is how it works, this is why it works.

I: Mmm-hmm. OK. So, do you think when you explain something, that you understand it better after you explain it than before?

S: Mmm-hmm.

I: Before you started talking about it, you didn't undertstand it as well as after?

S: Yeah.

I: Hm. OK. All right, so that's most of the multiple choices…

Next free response

I: So, this free response question talks about this… students often say they come away from a lecture feeling they understand a given topic, but if they try to do a homework problem, they get stuck. Has that happened to you.

S: Mmm-hmm.

I: Often? Why do you think that happens?

S: Um, I'm not really sure. I think maybe it's because he changes up certain things… it's not the same problem that it was… for some reason, I just remember torque really well. If he gave us an example of a painter standing on the thing… but then our homework was the seesaw. It's kind of the same basic concept, but it's not the same so you really have to… I mean, I understood when he did the painter and the cat on the board, and everything like that [Mmm-hmm], but when we had to do homework with the door, to figure out where you could push the door and with how much force… to get it to open, it's a lot different.

Background (35-39 are B, E, D, D, A)

I: All right, what major are you?

S: I'm physiology/neurobiology.

I: You're graduating now, right?

S: No, next year, I'm a junior.

I: OK, next year, next year. Are you applying for medical schools yet?

S: PA school.

I:	What's that?
S:	Physician assistant.
I:	Oh, I see, I see, cool. So, anything in this class you think will help you a couple years from now? That's the next question.
S:	Um, probably, I don't really know yet. I took cell biology, and it was like… we did the propagation of an electric current along a nerve and the 70 mV goes out and it drops… I don't even remember anymore, that was last year. But, I mean, I remember that… I know that they do kind of overlap. I think there's some stuff that will help me, but I don't think it's that important.
S:	OK, let's see the rest of these…
(glosses over the stuff about how she's been in [PER prof]'s class for two semesters, and the course was required for her major).
I:	So, these last ones are quick. On a scale from one to five, we give you one – very negative, what's your overall experience like in previous science courses? How positive was that?
S:	That's a really bad question, I would like to tell you so you can change it.
I:	Why?
S:	Science courses… I take biology, and I have to take chemistry [Mmm-hmm], they are two different sciences. I like my biology courses, most of my biology experiences are very positive, I enjoy them. I hate chemistry. [Really?] Chemistry is the bane of my existence. [Really?] I hated it. So, I think maybe you need to distinguish between both types of…
I:	Possibly, I think… I didn't write this…
S:	Yeah, when I got to it, it was really hard for me to answer because…
I:	I think the person that wrote this tried to cover all those bases by saying "overall experience", so if you had a horrible experience in chemistry and a really good experience in biology, they would balance out and meet somewhere in the middle [Yeah]. That's a good consideration, thanks for bringing that up. Um, how do you think your ability to learn physics was compared to the rest of the class, do you think? What was your impression of that?
S:	Um…
I:	Not necessarily in terms of what grade you got [right] but how did you perceive…
S:	I like… my other science classes.
I:	Compared to classmates, actually, well above average in this class, about average, well below, and so forth.
S:	I guess about average. It took me a long time to understand… a lot longer than other… like, a lot of other people would… when we did lenses, they came out of lab understanding converging lenses versus diverging lenses, but I still had to do the homework a lot and go on the website, and look at the lecture slides… it took me a lot longer to get a lot of that stuff. I think it just takes me longer in general, cause… I like having all the answers.
I:	OK. Um, do you think you were… this is the last one. Do you think you were able to learn other subjects better or worse?
S:	Better.
I:	Really?
S:	Yeah.
I:	What was different about… made that the case?
S:	I'm not exactly sure how to pinpoint… biology just makes sense to me, it just always has. I like… I like it, too, my microbiology classes, I like the little beasties… naming different organisms and figuring out what kills them and if they're anaerobic versus aerobic, graham positive versus graham negative… it just kind of clicks, and I kind of understand it, where I have to think about physics a lot more and study it a lot more, and chemistry classes don't ever make sense, so….
I:	I won't ask you about those.
(off task)

Honesty stuff

I:	When you were taking this, anytime you took it, maybe especially the last time, do you feel it was easy to answer honestly?
S:	Mmm-hmm.
I:	Did you get a sense from any questions in particular what he might want to hear… I know we tell you that it makes no difference, we're interested in what you really think, but…

S: Um… kind of, sometimes. I mean, we know what his goals are in the class. We know he wants us to think about things and not just memorize equations [OK], do all that, so I think… I mean, I don't think the questions are leading or misleading in anyway, but it's kinda like… you kinda know what he wants to hear. I don't know where it is… (looking through the test). Maybe on 29, a student has a limited time to study so he must do a few basic formulas and go into depth, or memorize… you know he doesn't want us to memorize everything!

I: Memorize everything… I see. So, were you able to… ever… I don't know how you responded to these kind of things before, but did you think… all right, this is what he wants to hear, but I think something completely different, so I'm gonna mark what I think.

S: I wrote what I think.

I: To hell with what he thinks. What he wants…

S: Yeah, basically.

(off task – discussion of other interviews. She briefly mentioned how honest responses are important, then the tape was stopped due to the interview ending)

Theo's interview

Interview: "Theo" MPEX2 survey, done on 6.7.02 at 1 pm.

I: As you know, this is just going to be an overview of this part [OK] of this survey. So, all we're going to do is… I'm just going to (pause) I'm just going to go through each of these, and you give your response to it, and indicate why you thought that, OK? Is there anything else I need to… (checks over some things) so I'll just read through something, and you tell me whether you agree or disagree, whatever reaction you have to the statement, and indicate why you think that. If I need something… more elaboration, rather, I'll ask for it, I'll ask for a specific example… so "you said this, but could you tell me what you mean, because I'm not really sure." If anytime, the wording of the question confuses you or is ambiguous, let me know then, because part of the reason we're doing this is because we want to know which questions are confusing or possibly worded improperly. [OK] So, anytime you see one of these and you're unsure what it's asking, say so, OK? All right, that said, let's just start at the very beginning. It should take just under an hour.

S: All right.

I reads question 1. (OR (original response): agree)

S: Agree, I agree. I use it for some of the stuff… elevators, and stuff like that, and how things fall, but some of the other stuff didn't really come in handy like the waves, and stuff like that.

I: The second semester stuff?

S: Yeah. [OK] First semester was a lot more helpful than second semester.

I: More helpful in terms of what?

S: For that question, everyday life.

I: OK, fine, applying things to everyday life, OK. All right, next one, then, I guess. I don't think I'm going to go for an elaboration on everything, that's not a very long one, if you give a reason for each one, that's good enough.

S: All right.

I reads question 2. (OR: neutral)

S: I disagree. [OK] The books were just horrible, both books were just horrible for this class, I had actually both books, I had his book and the Cutnell/Johnson book [mmm-hmm] and neither one of them helped at all for this class, on any of it, for both semesters actually. So, the problems for the homework, yeah, that helped a lot, but… you know, so that and going to class everyday is all that really helped [mmm-hmm] the text is horrible.

I: OK, so, you disagree with the statement because of the…

S: The text part…

I: Because of the part about the text. OK. Now, when you look at this question, is it just these three items you're considering: just reading the text, working out the problems, and paying close attention in class? Is that what you reacted to when you wrote the statement?

S: Yeah, and text more because that was first, too.

I: Text more because that was first… OK. Was there anything else that you needed to do that was important to understand the ideas in the course?

S: (pause) Um, going to class, I guess you had to participate too. I mean, paying close attention in class is one thing, but participating and trying to think through the problems in class, you know, I considered it… when I read the question, I considered that all one thing, relating it to everyday life, relating it to past experiences or past physics experiences, and stuff like that. I kinda included that when it said pay close attention in class, I was just figuring class, problems, and the text in that, so…

I: All right, OK. That's the kind of elaboration on the wording of the question I want to get at [OK], I mean, your first reaction was disagree because of just the first part. In addition to your response to the question, I'm interested in how people read these and how they see these things [OK], so that's why I ask. So, next one.

I reads question 3. (OR: strongly disagree)

S: No, I disagree with that. [OK] In this class, it really didn't come into play too much because we did a lot more concepts, but when we did do the problems that… if it's completely different than what you expect, then you… I don't trust my math enough to be like that, so I wouldn't trust the calculation over anything else. Not only that, but it's not just different, it's significantly different from what you expect. Not only that, if you're looking at your problem, and its significantly different from what you expect, even if the calculation is right and your math didn't mess up, then you really wanna fix how you're thinking about it, so that you don't think about every problem wrong… cause you might be, like, why… Maybe your calculation was right, but you should also go back and figure out why you expected something different, and why you were thinking about it wrong.

I: OK, so tell me if I heard this right. There are sort of two parts to this. One is you might not trust your math enough [Right] and the other is even if you trust your math, you… there might be something else you need to check?

S: No, I was just saying… the math could be right, [OK] but the reason you expected it to be differently was because you're looking at the problem wrong, if you expected… let's say in the first semester, with the force of one car being more than the other, you can expect it wrong, but even though your math is right, it's different from your original point of view on it…

I: So either your math is wrong or your initial expectation might be wrong?

S: Right, exactly.

I: OK. That's certainly fair, I hadn't heard anyone bring up that point, it's a good point. All right. Let's go to the next one.

I reads question 4. (OR: strongly agree)

S: Um, it has… not that it's not true, you need to make sure you understand that the formula is valid and that you can use it, but you also need to know when to use it, why you're using it, and the background I think is what helps you understand it a lot more than… the actual, you know? The formula itself… you know, if for instance, this semester we did that one where the particle went into the machine, and it gets shot around… it starts going around in a circle [Right] B naught, cross… you know that one?

I: Sure.

S: OK… final's over, I don't need to remember anything… just kidding. No, I couldn't remember our formula, but we derived it from all the different things, you know, like velocity for a circle is equal to this, and you come through, and you can kinda just know where everything comes from and why you're using it, and I think that's far more important than the actual formula itself, especially for me, I'm not going into anything, where I'll actually need the formulas anymore, but if I understand the concepts behind it, I can probably use it.

I: There'll be a point to address that later [OK] in terms of usefulness to what you're gonna be doing in a little while. When responding to this one, which part did you react to?

S: I guess the stress here is to use it in problems, because that's probably what affects us as students the most, and is kinda like how… cause it's one thing to see… make sure, I don't really think the emphasis is on the formula as valid as much as… you're asking whether or not… I read it as you're asking us if it's OK… once we figure out it's OK, we use it all the time in problems, and that's kinda how I read it. So, that's why I read it more than whether or not the actual formula itself was valid.

I: Yeah, all right, all right. So, next thing.

I reads question 5. (OR: strongly agree)

S: That's very important. That helped throughout the whole year, with the… with the elevators and the cars, and I guess the lab where we actually used the water to represent waves instead of just thinking about it theoretically, we could actually see something, even though the lab didn't work well. At least it was the idea of trying to picture things… it helps with the tests, and stuff, instead of just doing theoretical situations, like to actually grasp it. The only problem that you'd run into is things when you're… when you think that something would fall faster, you know… cause it weighs more, or something like that, but then to actually see it in class, where he would demonstrate that in a vacuum, they'd fall the same speed and stuff like that…

I: Did he do that first semester?

S: Uh huh. With a feather and a ball or something like that… and the monkey shooting thing, I mean, that's like fun stuff, but at least it helps you remember… [He did that too?] Yeah. [Oh] So it…

I: That is the second time you've mentioned this elevator thing. Can you tell me about that, because I'm not exactly sure what you're talking about.

S: The first semester we did a whole bunch of stuff on… it was actually on some of the test too, it's like how it feels when you're in an elevator, and stuff, and what the scale would read as you're moving up and down in an elevator, and stuff like that.

I: A scale reading.

S: Yeah, so everytime… I have the elevator in that apartment, and so every time you go in there you actually start thinking about, you know, the forces, and stuff like that… on your feet, and stuff like that. Just one of the ones that stuck with me.

I: Oh, OK. All right. So that one, that question seemed pretty straightforward [yeah] in being able to react to it. So, the next one…

I reads question 6. (OR: agree)

S: Not for this class. [OK] I mean, my friends in the other physics classes, that's all they know, are formulas, so I would agree with it for that, so I think that "physics problems" is kind of more general. Physics problems in this class… no.

I: So what do you take this to mean when we ask you… this is the main thing… to 'solve physics problems effectively', what do you think is meant by that?

S: Um, I would, I mean, reading it, it sounds like it's in general, which is why I think I picked a neutral when I answered it, or something like that, because it helps for this class, but I couldn't solve any of the physics problems that my friends had because everything was based around the formulas I didn't know yet.

I: Oh, they were doing problems using formulas you hadn't seen before?

S: Yeah, and it was more in depth than what I could just sit there and, you know, get on my own, you know, by taking what we had. We do it much more conceptwise than they did.

I: Did you show your friends our problems?

S: Yeah, they laughed.

I: Could they do em?

S: Some, and some they would have no idea. It's like… it took a long time to get used to [PER prof]'s style, and what he expects out of the essays, and stuff like that. But once you get used to him, they're fine, it's just… you know… in the very beginning, if you haven't seen what he's asking for, it's hard to go from pure formula based to writing an essay about it.

I: OK, did you look at this 'solve physics problems effectively' statement in a very general way, rather than… not specifically [PER prof] problems [Right] or [other professor] problems, I don't know what prof [right, yeah] your friends had. OK. That's an important perspective… what pops into your mind when you see 'solve physics problems effectively' will greatly influence how you react to that statement [exactly] agree or disagree… OK.

I reads question 7. (OR: strongly disagree)

S: I don't think so at all. I think one thing that Dr. [PER prof] was really good about was making sure we understood how it related to the other things that we'd gone over, and this is similar to this, this is similar to that… he would even, he would show it to us conceptually, and he would also compare it… you know, 'you don't need to know this, but this is the formula for that' and he would just show you how they looked almost identical, and stuff like that. So, I definitely don't think it was specific at all.

I: Are you mainly disagreeing with this first bit, then? "Knowledge in physics consists of many pieces of information…"

S: No, no, I think it's more this part… 'each of which applies primarily to a specific situation.'

That's the part I disagree with, you know? I don't think it's specific situation, I think that's one of the neat things is that… it can be used in such a wide range.

I: You mean one bit of information, one piece of information can be applied to lots of situations?

S: Right, right.

I: OK, OK, so, I think that's good. We nailed down where you disagreed with that. See this next one then.

I reads question 8. (OR: agree)

S: In some cases. With… like I said, I didn't remember that one… equation, that I was able to derive it from the F=ma, and the acceleration for a particle in a circle, and stuff like that…

I: Is this the particle moving through the quarter circle magnet?

S: I think so, right. So, for some of em I was able to figure it out given enough time, but the other thing is… we didn't deal much with equations, so at certain points… I remember, I missed the one with the mirrors cause I just didn't know it on the quiz… the equation for the distance of the mirrors, and there was nothing I had… in my head to derive it. I think if it's a base formula, like one of the main formulas… I mean, I would need to have known it, but if it was one of the ones that we were supposed to derive, and not one of those foothold ideas, then… yeah.

(pause)

I: OK. It sounds like you based the answer to number eight based on past experience… needing to come up with equations. Does that sound right?

S: Yeah.

I: OK, when you look at that… you just think back… all right, where did I have a problem coming up with an equation? Was I able to come up with it?

S: Yeah, exactly, and sometimes I was able to, and sometimes I wasn't, and, you know, I had plenty of time on that quiz, and I just… you know, I couldn't think of it, so I got that one wrong.

I: So, this next one then…

I reads question 9. (OR: disagree)

S: Um… I think the point of physics is to understand the real world, so I think the connection is the whole point. I mean, I couldn't… I mean, I think some things could be theoretical, when we got into the quantum toward the end, you really couldn't make it click… entangled states, or whatever, where two things can be at the same place at the same time…

I: You talked about entangled states?

S: Well, kind of, I've taken some quantum stuff, so I knew what he was talking about, he kinda kept it in general, but it's just that kind of thing where… so some physics, I guess you can learn without it, but I think the majority, for this class at least, was related to the real world. So I would… I mean, the question is pretty straightforward…

I: And your response is based mainly on your experience in this class…

S: In this class, yeah.

I: where a lot of the stuff you were able to…

S: Yeah, exactly.

I: That's fair. All right, let's see this next one, I guess, it's this problem solving thing…

I reads question 10. (OR: disagree)

S: Again, the same problem as before… in physics, or in physics for Dr. [PER prof] classes… it's slightly different. I mean, if you showed me a [Professor] test, I might not be able to do it without, without matching up with a problem I had seen in the homework, I mean, that's how everyone I know studied for his class, was to… was to, do practice problems over and over and over again and then relate it… but, so they're general 'in physics,' but, for physics for two semesters with [PER prof], I would disagree, saying that, you know, we hardly ever just matched problems as much as used concepts to solve everything.

I: OK, OK, that's fair, so when taking the survey, is that what you based your reaction on? Your experience in [PER prof]'s class?

S: Yeah, because I had him for both semesters.

I: OK, OK. So…

S: But the question itself is hard to read, it's… I stayed consistent… I wouldn't flip flop just saying physics in general and physics in this class, but, that's why I wouldn't put "strongly disagree" and I'd stay kind of toward the neutral side.

I:	So that's… that's an issue that might come up here. You said you were trying to be consistent. In what way was that, I mean, were you basing all of your responses based pretty much solely on your experience in Dr. [PER prof]'s class?
S:	Well, no [or something else], well, I think… I… more on Dr. [PER prof]'s, but I do consider… you know, when it just says physics, not 'how would I pass this class'… because here it says 'in class, in class, in class…' but here it just says 'physics in general', so because of that… you have to…
I:	So, because 'physics in general' doesn't refer to the class itself… [Right], then you might think about it differently?
S:	Exactly.
I:	Hmm. OK, that's a pretty subtle distinction, we'll have to look at that. We'll see this next one here…
S:	You see? This one starts out 'In this course…'
I reads question 11. (OR: strongly disagree)
S:	So, in this course, I strongly disagree, I mean, instead of just being somewhere neutral, I would say that in this course, everything came from… um… taking your instinct and matching it with what was real, and trying to… just not throw away what you think is gonna happen and just see if you can, you know, make it fit for what you think's gonna happen, you know, you know… just change the way… the word's slipping out of my mind… anyway…
I:	Visualize?
S:	Well, no… just try to, you don't want to throw away your intuitions, cause a lot of times, it can lead you on the right path, and just because it didn't get you there right away, you can just slightly change the way you're looking at it, cause your intuitions are gonna be there no matter what, so you learn to go from your original intuiton in the proper thinking from there.
I:	Right, let's see… (pause) that's all I wanted to talk about on 11. Next one.
I reads question 12. (OR: neutral)
S:	Um, I disagree cause I think the whole point of working practice problems is to get you thinking about it, and, um, going through… I mean, to get your mind starting to learn how to think about these problems, that's the whole reason you don't just show up and take a test, that's why you have homework, is to get your mind ready to work through these problems on a constant basis [Mmm-hmm]. And so, to do practice problems and stuff like that, if you get two different approaches, you're gonna wanna know what was good about each approach, and what was bad, and… in situations one would work, and where the other one would work, so… I think, you know…
I:	Was there a hangup in the statement of the problem… having a sentence 'after looking up the right answer', because you weren't able to do that?
S:	Yeah, I mean, it's kinda funny, I mean, I understand what they're saying, I mean, looking it up could just be as much as after it's posted, you know? [OK] I mean, if you look back at it later after it was posted, and there was two different ways of getting there…
I:	Well, hopefully, by the time you've handed in the homework, you've selected one approach you like better for some reason [Right] and have handed that in. You keep your old work, too, or… sometimes have two… two different worded…
S:	When I got hung up, I'd put both… I mean, I would just write out saying 'well, if I look at it this way or I look at it that way…'
I:	On homework?
S:	Mmm-hmm.
I:	Hmm, I don't remember that happening a lot (*ed. Note: I (transcriber and interviewer) was this student's TA and I only said this because I don't recall him ever doing that on his HW.)*
S:	Well, more last semester than this semester, then, I guess.
I:	I don't know, I'm already starting to forget what everyone's homework looked like. Yeah, no more grading until the next time I teach this class… which will be fun, we're doing 121 again, so…
S:	Oh yeah?
I:	Eight sections. Mostly the same TAs too.
S:	Well, at least you guys can start reusing some labs and improving them and getting them to work…
I:	We are, we are. We know which labs worked better, and the advantage is this time is we don't have to write a lot of these new from scratch anymore. We have some that we know worked OK,

we only have to mess with the ones that weren't ideal the first time.

S: Yeah, it's the… the labs were not helpful. [OK, well…] We'll get to that later, go ahead.

I: Maybe, I don't know. Let's see…

I reads question 13. (OR: disagree)

S: Again, 'in this course' stands out…

I: So that's a red flag?

S: Yeah. And, the insight and creativity have a lot to do with it, so I strongly disagree. I mean, at least half the test is always an essay question on… there's always the estimation and there's always the straight up essay question, and the two of those always have creativity and insight, because there was no real right or wrong answer for the… for the estimation, as long as it made some sense, and, you know, you could think… if it was that power problem in your house, and you're just like, we'll, I have this many lights, or something like that, and you just had to think through it… so I don't really think that, uh…

I: OK, so aside from the 'in this course' phrase raising a flag, you're reacting mainly to the last part of it [right] insight or creativity. Do you think that your grade is partially determined by how familiar you are with the material?

S: Some of it, I mean, I felt that… more on the homework than the tests, I think so, because by the time that the test came around, we felt pretty comfortable with the amount of material we needed to know, and then the creativity took over. But, for the homework, people that were taking MCATs and already knew how to just do the straight up physics, they had a slight advantage and always got three points higher or something like that. They would get 13's when everyone else got 10. [OK] They had physics in high school, or something like that.

I: OK, the only reason I'm pointing it out… that bit about being familiar with the material is that people can agree with that part, but if they see 'insight or creativity will have little to do with it,' they'll strongly disagree with the whole statement based on the fact that they strongly disagree with just that.

S: Right, yeah.

(I at time 130 discusses other student responses that are unrelated to S's responses.)

S: In lab, we got no credit for the actual experiment, it was all the lab report, so I really disagree with that, because we were creative a lot of times, one time, last semester, we had… everyone else used a ramp, we're the only group that decided to use the k constant and tried a spring for that one marble… shoot thing… you know… and, and so, we got no points for that at all. None. And then, you know, [TA]'s a pretty tough grader on the lab reports and the lab notebooks, so we ended up getting a bad grade no matter how creative it was, so I disagree with that, as far as the lab's concerned.

I: All right, that's unrelated to this, so let's go on to the next one.

I reads question 14. (OR: disagree)

S: I disagree, because the one principle in the very, very beginning was when… when a truck hits a car, or something like that… it didn't really make too much sense, they were hitting back on each other equal, but once you tried to make sense of it, it actually, you know, you could actually make it make sense, and how're you're just like… it goes back to that intuition problem where you know… sure, the little car will more move more, because it's got a smaller mass, and that's more like the reaction from the force, but it doesn't mean the forces weren't equal to begin with, so… I mean, that's just a straight out example, but, when I read that question… in the, what, 700 times we've done this, this survey, that's the one I always think of from the beginning, so…

I: The truck example, the truck and the car, comes up a lot when, whenever you think of sense making?

S: No, no no, when a physics principle doesn't originally make sense, and then you, and then… see here, it's saying, then you just accept it and move on, and that's not what I do, you know, you just…

I: So you use an example of a case where it didn't make sense at first, but after working through it, it made sense eventually…

S: I reconciled it, yeah.

I: OK, OK. That's fine, it's good that I know exactly how you're using that example, cause it comes up a lot. All right.

I reads question 15. (OR: neutral)

S: Um, I mean, I disagree now, absolutely, cause… I don't think we ever really practiced too many estimation and, I mean, we did estimation, but not the same way it was on the test, and we never really saw the ones… the essays straight out, like, what was that one with electric potential energy or something like that? And we had to compare it to just potential energy… compared to… what was the name on the last test?

I: You had to know the concept of potential? [Yeah] Electrostatic potential?

S: Yeah, electrostatic potential. Yeah, exactly, so… it's like we hadn't practiced too many of those problems, but we were able to handle it by just thinking through it and creativity, you know… but, the calculation problem was like everything we had always seen, but, you know, that was straight out… just like everything we'd practiced over an over again.

I: OK, so to react to this, you drew on your experiences of exams in this class?

S: Right.

I: OK. All right, so, part of it relies on the context of the questions you know he'll give you, or the kind of questions…

S: Yeah, I mean, it says "on an exam" not necessarily… I don't know, I didn't read it as being general. I figured it was in this class.

I: Maybe that's fine, but I just want to be sure. Let's see the next one.

I reads question 16. (OR: strongly disagree)

S: Exact same thing as, I think… you know, 14, where… it's the same thing, whether or not… whether or not she's reading the principle or got it in class, I mean, it's the same thing, you need to reconcile it…

I: So you read 16 and 14 as basically saying the same thing?

S: Yeah.

I: Or asking the same thing?

S: Yeah, absolutely.

I: OK.

S: That happens a lot.

I: OK.

S: and seventeen…

I: I find it… it's good that you say that, I find it a little surprising, though, because on a previous question, how you reacted so harshly against the usefulness of the book…

S: Well, just because *I* didn't find the book…

I: Fine, but you weren't reacting to the statement about the book in number 16, you just saw its similarities to 14.

S: Yeah, either that it was so close to 14 when I was reading it… or the other thing is… if she's having trouble getting things to make sense out of the book, too, like everyone else, well… I mean, it's not like you're saying the book is wonderful in that question.

I: We… no, we try to make questions that are neutral with respect to the book we use. This should be able to be used for a bunch of different physics classes, and not just ours. We've given similar versions of this to other universities, and so forth. All right,

Question 17, and an interesting comment (OR: neutral)

so 17… you were pointing to this one [Yeah, I mean…] why?

S: Yeah, the most crucial thing in solving physics problems is finding the right equation to use… is just very similar to the questions earlier, here, where it was just… "the main point in seeing where formulas come from is where a formula could be used." I don't know… "problem solving is matching problems with facts or equations and substituting values…" number 10, it's like the same question again. It's just… said a different way.

I: You treat those all the same? [Yeah] all the same way? So, do the slight differences in wording make any difference?

S: Not really, cause again it's saying 'solving a physics problem' so I'm just figuring out in general… you know, are physics problems finding the right equations to use, so for our class, not always, and just in a general physics problem, yeah. You would need to know the right equation. So I imagine it the same way… where I can't go strongly agree or strongly disagree because… in general…

I: OK, so… so supposing… suppose that you treat it like the other ones, you said it was just like… right? [Mmm-hmm] Did you treat those other ones in terms of the specific class or in terms of more general…

S: If the other ones just said… [red flag drawn up…] Yeah, it was the same thing… physics is related to the… can you solve physics problems… I read it the same way, as "a physics problem." If it says "a physics principle" or "a physics problem," then I'm gonna just think of it generally, I'm not gonna think… in this class, you can solve it, so.
I: OK, so, let's see the next one then.
I reads question 18. (OR: agree)
S: I mean, yes, as long as… when I handed in the ones for us, I felt like… I was never really surprised when I got it back one way or another, but… I mean, the one thing with this class especially is, you have to keep calm as far as… you may think you did really bad, but after the curve it ends up being a decent grade, so… a lot of times you come out thinking, "Oh, I did bad," then you get it back, and it was a 65, but that's a B…
I: But the curve aside, you did get a good sense of?
S: How many points I got, yeah.
I: Of how you did… roughly, not what the curve is gonna be [Exactly]…
S: The only one that I really got… I did a lot better on the mirror quiz than I thought I did.
I: Yeah, I think the scores on that were pretty high [yeah], I didn't grade those.
S: I only got the one problem wrong where you actually needed that formula that I didn't know yet.
I: Yeah, OK. 19, then.
I reads question 19. (OR: neutral)
S: Um, I disagree, that's what I think… the lecture was the good part about this class… I got all the concepts, and the general parts, you know, very well from [PER prof], just dealing mainly with concepts and… he didn't really… he did some proofs and one or two problems, but he didn't really spend a majority of the time on problems, and that helped a lot. I mean, that being said, I also don't think that means we shouldn't have a discussion where we do go over problems, you know, and where discussion, you know, is taken away and we suddenly have to go to office hours for that, and… it's just, you know, cause I think that's one thing about this class, you *had* to go to office hours if you expected to do well, and so, I think it is important to go over problems, but I don't necessarily think that that's Dr. [PER prof]'s responsibility in lecture.
I: So… so, you're reaction to this, it sounds like… was it based on the part 'instead of spending so much time on concepts, proofs, and one or two problems.' [Right.] Is your impression that Dr. [PER prof]'s class was mostly structured around this second line? [Yeah, absolutely.] And your reaction to the statement, then, was based on whether you liked or disliked that approach?
S: Right, exactly, I mean… but if… I dealt with it because it said 'in lecture', so I stuck with just… in lecture, I think it was great the way he did it, I mean…
I: Would it have helped much more to have done more problems in lecture.
S: No, but if it had said "in this class, more problems" then I would say that it's a different story, but since it said "in lecture," then I think the lecture was fine, I don't think that was the problem with the class.
(pause)
S: It's those TAs!
I: That's what I was gonna say… "the whole class was great, except for those parts the TA was doing."
(off topic – discussion of TA comments and structure of the class. Not germane to the MPEX at all – time ~236)
I reads question 20. (OR: disagree)
S: Again, 'in this course' stands out, and I don't feel that memorization was anywhere near what the other classes had to do, it was much more concept.
I: OK, so it was for this course. Was it a problem at all?
S: Not really until the last part of the second semester, just cause… it really wasn't this class, it was just that I was… I was just so swamped with everything else, I didn't have time to sit down and learn the last few formulas at the end… about the mirrors, and stuff like that. So, no, it was never really a problem. Not for this class.
I: OK, that's pretty straightforward then, let's see this next one.
I reads question 21. (OR: disagree)

S: I don’t think so at all, I mean, I don’t consider myself the most amazing student ever, but I’m a decent student, and I think that the whole point was to give yourself… the lecture was there to introduce you to the examples, get you used to it, but I think the whole point was to start thinking about it at home, that’s the purpose of the homework and the purpose of the… you know, labs and stuff, is to start thinking about it outside of class and not just in class.

I: OK, so, this is referring to what one might need to do to understand…

S: I mean, I don’t think it has…

I: For this course.

S: For this course, but in general for any course, if you… you can’t just go to lecture and learn stuff, I mean, you have to think about it throughout… you know, at home, and one good thing about having it associated with real life examples is when those real life examples… like the elevator, every time I step into it, it’s a real life example, so I start thinking about it again, and… it….

I: Lighter or heavier… depending on where you are. Had something on the tip of my tongue, but I just, I just forgot it… so, let’s see this next one, then.

I reads question 22. (OR: disagree)

S: I read this just like I read all the all the other ones about whether or not you can apply it to…

I: So, to number 1, for example, 9… [Yeah, exactly, exactly]. One and nine, you look at those, are those the same to you?

S: Right, yeah. I read it the same way, it’s just slightly worded a little bit differently, and you threw in lab in this case, but I still think it’s the same question.

I: OK, all right.

I reads question 23. (OR: neutral)

S: Sometimes, it’s according to what the topic is. I mean, for the most part, if… I would say that a majority of the cases we were… when we got together in groups to try and do the homework, we were able to talk through things… what about this, what about that, this happens, that happens, but every once in a while, especially when we got into the more theoretical, less real world stuff of second semester, it was a little bit more difficult to even talk about it, because we’d just all say ‘I dunno’ and we’d have to come in and ask questions. So, the majority… I disagree with the statement because… you know, you could all talk through it and maybe you could figure it out together, and brainstorm, and help each other out, but…

I: OK, you disagree with it because you found a counterexample to this? [Yeah] Here’s a case where not everyone knows what they’re talking about, but you were able to get some benefit from it.

S: Yeah, we did a lot of group work, and hardly any of us automatically knew going into it everything…

I: This was in office hours mostly?

S: No, we used to get together for group work to do the homework, we used to get together in a study group to work on the homework.

I: And this is mainly homework problems you’re looking… and not so much the groupwork you do in, say, lab or discussion?

S: No, that’s not how I read it.

I: Well, that’s fine, I mean, I want to know how you did it. You thought of your group experiences doing homework, and not other things.

S: I guess if it said specifically lab, I would have thought about that, but when I hear groupwork, I don’t necessarily think of lab.

I: OK, maybe that was the point of phrasing it this way, like I said, I didn’t write these, but I want to know how they run(?) So, what’s next?

I reads question 24. (OR: neutral)

(long pause)

S: Um, I mean, understanding the big ideas… I guess I would disagree because, I mean, any time it says ‘but not for’… Understanding the big ideas, especially in this class, is how you understand any of the problems, but since it said “regular physics problems,” I really haven’t looked at many from the other one, so I couldn’t say with certainty, but the way I would have to deal with the question is my own experience with my own physics problems, I mean… understanding the big ideas is all we really tried to do until we got to the specific questions, and we went… and we worked our way in. We didn’t really look at a hundred examples and then tried to grasp the big idea, we usually tried to grasp the big idea and then match it up to different situations.

I: OK, so based on that experience, you disagree with the question then?
S: Yeah.
I: Now, can you do that because you perceive what we say as being “regular physics problems” as being different from the ones you’re used to doing on homework every week?
S: Yeah, I do… that’s not… I was… I disagreed more because of the “understanding the big ideas would not be helpful on other things” which is not the way I look at it, but I do not… if you just ask me… I don’t like the wording, but not (garbled)… regular physics problems, I guess I wouldn’t consider the ones we do normal.
(I discusses the possible need to flip the tape.)
I reads question 25. (OR: disagree)
S: Again, I read this identical to every one of these equation questions that we’ve had.
I: OK, so what might those other equations questions be?
S: Let’s see. Number 17, “the most crucial thing in solving physics problems is finding the right equations…”
I: 17, and 11, maybe? 11 from this one, what other ones had equations? 6, perhaps?
S: Yeah, yeah, exactly. They’re all just the same question written different ways, so I don’t read them any differently.
I: OK, OK. So this next one, then…
I reads question 26. (OR: strongly disagree)
S: I agree only because I ended up just studying off the posted solutions more than comparing to my homework, cause it was so soon… it wasn’t posted three weeks later that I couldn’t remember my train of thought, so I was able to think through it a lot, you know, pretty easily from the posted solutions.
I: And you didn’t refer to your own graded stuff at all?
S: Hardly ever, yeah.
I: OK, maybe I’ll spend less time on that next semester (chuckles). It’s not a whole lot of work writing little comments, and writing little comments is better than nothing, or five or zero. [Right].
Begin discussion of question 27. (OR: C)
So, we’re done with the strongly disagree to strongly agree questions. The rest of them are just multiple choice, most of these dialog ones, I mean, you’ve seen these a bunch of times, you just read the dialogues and decide who you agree with, or just pick one of the options, A through E, so, I’ll just let you read through the Meena and Salehah dialogue first. Number 27.
(long pause)
S: Yeah, I would agree, maybe toward B or something. I think that Meena’s got the right idea, where everyone can talk together, and…
End of side 1. (approx. 400 on the timer.)
Begin side 2, continue #27.
S: thinking it, and it just doesn’t end up being worthwhile, when you can move on and try to figure out another concept, I mean… still working?
I: It’s working.
S: After a while, you do need someone to have some insight so you can at least get something accomplished, which is… when we did get frustrated, it was because it was a concept we couldn’t figure out on our own, you guys weren’t allowed to tell us, so… so, I mean, I think you did need someone that could have some insight, or something.
I: All right, so, let’s look at the Tracy/Carissa dialogue.
Begin 28. (OR: A)
(pause)
I: Talking about textbooks. (S chuckles.) What’s so funny?
S: It says textbooks…
I: Hmm?
S: (long pause) I don’t think either relates much to our textbooks cause they just weren’t good to use, but a *good* textbook, would, I think Tracy’s got it, with A, you know? I think relating the… relating it to other things, maybe you understood the other one, and that’ll help you with this, or… if you treat everything as separate entities, it’s like… it’s not a like a building process any longer, on working through it, it’s suddenly just, you know, learning it and moving on. Putting it all together… it’s just like a building process when you learn math, you need addition to learn this, and then you

build your way up, and so, I think that a good textbook would… wouldn't treat everything as just separate, and actually try to relate it with each other.
I: OK, so do you agree with the first thing Carissa said: "Different topics don't always have much to do with each other?" Do you agree with that statement or not?
S: I mean, they don't always, but that doesn't mean that the textbook shouldn't try.
I: Oh, OK, you still basically agree…
S: With Tracy.
Start 29. (OR: A)
I: All right, let's see this next one. These next two aren't dialogues, so… which of the following options, which option should the student choose? This is to do what? You're just studying and trying to choose between the following options…
S: Well, I mean, I would lean towards A, so either A or C, which is "leaning towards A". I mean, the few basic formulas and going into depth with them and truly understanding them, I think, is a lot more helpful because you can derive other formulas from it, and in most of the cases, when you have a hundred formulas, they all came from one anyway. And if you know something more in depth, then at least… I don't know. On strictly like a points… you know, what grade you're gonna get, if you get something completely right, it's usually gonna be a 20 point question compared to two points here, two points there, so…
I: So, when you looked at this, what did you… did you have an assumption about what the goal of the studying was?
(long pause)
S: Did I have an assumption? I don't…
I: This is assuming you have a limited time to study…
S: What was the…
I: Study for what? [Oh, OK.] What did you think?
S: I guess my assumption would be to perform well on the test, yeah.
I: So, they were studying for a test specifically, and trying [Right, yeah] to do the most productive thing to get a good grade on the test.
S: Exactly, yeah. That's the assumption I took… that's what the question was asking.
I: OK, all right.
Begin 30. (OR: A)
S (looking at the next one): My favorite question!
I: What?
S: 30's my favorite question!
I reads question 30.
I: Why is this your favorite question?
S: Cause it's… it's A! Undoubtedly, it would be the most helpful thing that could ever happen to me.
I: You think so?
S: I think I've laughed out loud every single time I've gotten to that question, we've done this thing like 30 times. I really do.
I: I told you a thousand times not to exaggerate.
(S laughs, not at I's comment)
S: Um, I guess… the people that were born with photographic memories… it's different than if we could just get it now and we could just use it and just read through it and know… oh, that'd be so wonderful! It'd be the greatest thing that ever happened to me. I'm sorry. I understand what you were trying to go for is that… you don't necessarily need to memorize to pass things, 'cause…
I: Hey, I'm not the teacher, I'm just… I'm evaluating…
S: The way that question is written, it would be the most helpful thing, I mean, I didn't take the question very seriously, I guess, cause I thought it was the funniest thing I've ever read, but… I definitely, I definitely have chosen A every single time.
I: I'm sure if I went up and checked real quick, that the numbers would agree with you.
S: Yeah.
Begin 31. (OR: C)

I:	I haven't heard such a strong humor reaction to any of these questions before, so… let's see… 31. So you gotta read the statement about what the horse is doing, and then you have to indicate what best characterizes your attitude towards studying and answering questions like this one.
(long pause)
S:	Well, I mean, I would say something like D or E where they're… they are quite helpful, because not only… cause it doesn't directly come out… it's not just a question… what is the force of this being applied here, it's trying to relate it to a whimsical real life… you know, not a real life, a horse wouldn't talk, but… unless it's Mr. Ed.
I:	You're the second person to mention Mr. Ed.
S:	Or what was that movie with Bobcat Goldthwait with the horse? Hot to Trot?
I:	I didn't see it.
S:	Anyway… John Candy was the horse, and Bobcat Goldthwait was the jockey, but anyway, but I mean, it's a whimsical way of looking at it, but it still gets you thinking about the concepts as a whole, and how you would relate it to things, but at least it goes back to… OK, he has a point, and it might be something that your original intuition would say… "that can't be right, because it wouldn't move!" And then, that's when you have to reconcile your intuitions to what's really happening or why it doesn't move, and, you know… [OK] will that force compared to this weight…
I:	So, did you end up looking at questions like that when studying for tests, or did you study more from…
S:	Um, I was kinda forced to look at questions like that cause I studied from homework and old tests, and those were the kind of questions…
I:	You thought there was a lot of questions like this?
S:	I thought there were some that were similar to that one [uh-huh] for instance, what comes to mind is the one where the guy said "I can throw the ball up and then stand on it, and throw it up, and stand on it, and get myself to the moon.
I:	Oh, right, right. Cool, OK. That was from a while ago, I'm surprised you remembered that. All right.
S:	That's what I'm saying, it gets you thinking, and it's something that, you know… (garbled) [So] So, now, coming from where you are, do you read that as Roy (pronounced as if it were French) and Theo (Ed. Note: This is a hockey reference.)?
(Off task – hockey digression.)
Begin 32.
I:	So, read the dialogue between Roy and Theo.
S:	Yeah, I did.
I:	So, what are the advantages of working with each?
S:	All right… the advantages of working with someone like Roy… is that he has read the book, and he has fairly… a good memory, considering, you know, I can't understand three sentences in that book, so the fact that he can go through and go, and actually be able to connect concepts with formulas is helpful, because at some point, you will need the formula and, you know? And then you need to work with someone like Theo, where he's trying to make sense of the formula and not just treating it as, you know… the formula… I read this as just like the other ones but just as a real example [OK] and it's just… Roy is good because he knows which formula that you might need to use, he can relate it that way, but Theo is the one that's actually trying to reconcile it with his intuitions, and because of that, I think that he'll remember it longer, and understand it more when more in depth questions come.
Begin 33. (OR: C)
I:	OK. So what's you're reaction to 33, then? **I reads question 33**.
S:	I always said C. Cause I thought that you would want to work with one that's got a little bit of both in them. Because you want someone that would be able to bring up the formula if you, you know, couldn't understand and gave up on trying to read the book, and you're gonna want someone that can actually make sense of it for you and try to talk it through with you so you can try to grasp it instead of trying to memorize all the formulas.
I:	All right. We're close to the end, let's see.
Begin 34. (OR: B)
I:	So, read the dialogue between Carmela and Juanita. Who do you agree with more?
S:	I kinda agree a little bit with both, because I feel…

I: Equally with?
S: Yeah, I would say equally, I mean, I feel that explaining it to other people does help you in times, but at times… sometimes you just really need to sit on your own and try to get it, because you can spend more time on the stuff you need to when you're on your own, but, you know, if you don't get something… if you don't have any understanding at all, explaining it to other people might not be as helpful, but that doesn't mean that you wouldn't want them to explain it to you, but at other times, I've needed to just… like, when studying for a test, for instance, I would get together with the same group I did the homework with, and we'd go over everything, but I would write down things that I was having a little bit of trouble with, or didn't quite get, and then I'd make sure I got those concepts, and then I went home.
I: All right, then. So, this is a free response.

I reads the free response on getting stuck on homework.

I: So, does that happen to you?
S: Yeah, all the time.
I: Why do you think it happens?
S: Well, I think I get the big concepts, and and sometimes I might have a little bit of trouble relating it to the specific case on the homework, but the other problem is, and he worked on it really hard this semester, but by not having that problem due right away, or something like that, but last semester, for instance, he definitely definitely definitely… sometimes had homework problems on concepts we hadn't gotten to yet. And so those were the main times I got really, really stuck on the homework.
I: OK
S: But it's not necessarily a bad thing, to get stuck on the specifics, cause then you start thinking through it and using the big example in a small situation, but that's again why I would want a discussion section.
I: It's slightly different from what was asked, I think. I mean, you're describing something where… he didn't get to a topic yet, so when you're trying to do a homework problem on it, you get stuck. This one is assuming that you've seen a lecture on it, and you came away from that lecture feeling that you understood it.
S: OK, I mean, I understand. You understand maybe the big concept, and when you actually have to apply it, it's sometimes difficult, and then, you know… I don't think it's a bad thing, I just think that the actual thought process on how to get from such a big concept into actual application might take you a while to get there, and… and that's why… you get together and you go through some of these problems… but (whispered) a discussion section might have helped…
I: So, you're agenda for getting a discussion section… (laughs)
S: It's not gonna help me any now, so I don't really have an agenda! It's really just my complaining.
I: Well, at least you admit it. All right.

Next free response

I: So, what, if anything, did you get out of this that will help you in your chosen profession? You're pre-dentistry, is that right?
S: Mmm-hmm, I just think it's more like… I mean, the only real things that truly apply are the problem solving techniques, I mean, I don't actually see myself using until the very end maybe X-rays or something specific physics things in my profession, but the concepts of using big concepts, applying them into specific situations, the problem solving, not getting stuck just cause you haven't specifically seen that situation before, and kinda trying to relate stuff from other things into solving the problem that's at hand.

Background (35-39 are B, A, D, A, A)

I: OK, so you had 121 with [PER prof]?
S: Yep.
I: Is it required for your major?
S: Uh huh.
I: Now, did you put C for this? Do you consider yourself premed?
S: Yeah, yeah. Premed.
I: It's all the same? OK. So, overall experience in previous science courses, how would you rate that on…

S: Previous? Somewhat positive, very positive, yeah.
I: OK, OK. So, what about the last two, then? Your ability to learn physics compared to the rest of the class… for this class.
S: For this class, I would say A or B, better than average to top people…
I: So what about your ability to learn other subjects compared to physics?
S: Well, for this… other subjects compared to physics… I take… somewhat greater. B. I feel like I can… I think that's just in general, it's why you picked physics and I picked science, it's what interests you more, and if it interests you, you have a better ability to just sit there and learn it. You want to learn it more than…
I: And so, do you have this desire to learn the physics more so than other subjects you take?
S: No, the other way around. Compared to my ability to learn physics…
I: Oh, OK, so you said what you meant. So, what's the reason for your confidence in your ability to learn physics, you said you'd put yourself in the top…
S: Because I was one of the only people that would ever talk in class and I mean… some of that is just not my fear of raising my hand, but when other people sat there dazed and confused, and when it came to turning in homework and people scrounging for, you know… "I don't get this, I don't get this…" or before a test when people'd just get nervous. You know, my results on the tests were pretty good, I got As on both tests, and the quiz and the test, and stuff, so I felt pretty confident how I understand the concepts compared to the other people that I was talking to.

Honesty stuff

I: Having taken this four times now (S. chuckles) were there points while you were taking these… four times, this is the fifth, right?
S: Isn't it sixth?
I: You take it before and after each semester…
S: And then once in lab two, right?
I: No, you never take it more than twice… this is the fifth. Were there questions you found you had difficulty responding to right away when you were looking at it?
S: I remember the first time through, the first time through, I think I was more like… I didn't really know what you were quite getting at with some of the questions as far as… just the stuff as far as (pause), I didn't really quite understand the difference between the formulas and the big topics, and stuff like that, but once we started getting into it, I mean, I understand how, you know, [PER prof] was different than these other teachers, and stuff like that. But before you've even experienced it on the first day, it's kind of weird cause you've never seen physics problems really before; or at least, I haven't, I've never taken physics before.
I: You've never taken physics before?
S: I've never taken physics, yeah.
I: So, that's interesting. So, after the first semester, you had an idea of what this class was gonna be like. Do you think that made it more difficult… or at least, I don't know how to put this… was it more difficult to answer frankly to the questions the second, third, and fourth times you took it based on what you thought his goals for the class were.
S: Did you think I was just answering it because I knew what he was looking for, is that what you're saying?
I: Um, well, that's part of it, we've seen… I've asked people similar things, and they say, "well, I answered…" In one case, I had someone say, "the first time I took it, before I got to know him, I sort of made a guess as to… if you're a physics professor, what do you want to hear?" Maybe what I'm asking you is, do you know pretty much what he wanted to hear after the first semester?
S: Oh. Well, I mean, I guess I did, and it made certain questions harder to answer, like, the ones that say, "physics problems are easy to understand…" you know, that's why I think I had trouble with those questions that don't specify whether or not it's this class or not, because I would agree with them, that his problems, you can solve with big concepts and not too much of the little stuff, but when it says 'physics problems', then I'm torn between what his goal was and what physics problems…if it was on a department final or something like that, I think I'd have serious, serious trouble with [professor]'s questions.
I: OK, all right.

Appendix C: FCI split task interviews

Christine's interview

Interview: "Christine" for FCI survey
Interviewer: Tim McCaskey
Done on 10.10.03

Prelude

I: I guess, completely unrelated to this, how do you think the test went?
S: I dunno, I think I was confused on the whole vector one.
I: Which one, you mean the one…
S: The mouse.
I: Find average velocities and stuff like that?
S: Yeah, I wasn't ready for that. I figured we have… like we all talked about, ok, we're gonna have this, we're gonna have that, you know what I mean? We'd all figured it out, and that wasn't on. We did all the old exams, and we did all of that stuff, so…
I: So what about that one was strange?
S: I wasn't exactly sure what kind of answer I was giving, you know? Like… what my answer should look like.
I: Oh.
S: You know what I mean? Whether I was doing more of a vector or if I was just doing a number or if I was…
I: I mean, the instructions said to put it in terms of i and j
S: Yeah
I: i hat and j hat, so if you did that, that's the right form.
S: OK.
I: And it needs units too, so…
S: I put it… I put an answer in i and j, but no units, and then I also just put in a number because it was kinda… (mumbled)
I: There needed to be units, but the i and j is the right idea for a vector.
S: Oh, ok.
I: That's how you demonstrate how long a vector is and that's all velocity was, so.
S: Oh.
I: Anyway, I hope it goes OK for you. I guess a lot of people… I mean, we had a lot of questions to answer during the test as you probably saw, we were both kind of going crazy.
S: Yeah.
I: This is related to this thing (points to survey) you did, do you remember that?
S: Yeah.
I: OK. We'll get to the specific stuff here in a little bit, but how you did on this and how you're gonna do on it when you do it at the end… those aren't graded, and so these are just participation surveys, and so that's why I don't comment specifically on whether or not you got these right, cause we'll see at the end how you changed.
S: OK
I: If that makes any sense. Just some general things, then.

General stuff

I: What year are you?
S: Third.
I: Junior?
S: Yeah.

I: OK, majoring in what?
S: Marine biology and psychology.
I: OK. What… so you're doubling?
S: Yeah.
I: What did you want to do with that?
S: I don't know, that's why they're both… (laughs)
I: So they're not necessarily related?
S: No, it's to open as many doors… I have always done marine biology and I just added psych because I don't know what I want to do with marine, and so I figured if I add psych, I can still graduate on time, and it opens up a whole 'nother series of opportunities.
I: So, why are you taking the class?
S: This is required for bio.
I: It's required for bio?
S: Yeah.
I: For marine bio, but not psychology?
S: I don't… no… well, I don't know, I don't think so. Maybe if you want psychology as a bachelor of science
I: Oh, OK.
S: It might be, but because I'm already doing a science, I don't have to pay attention.
I: What level psych are you up to?
S: Oh, I just added it last semester.
I: So you just took a general class?
S: I took PSYC 100 way back when in my freshman year, and I like it, and my mom is in psychology.
I: Oh.
S: So I know I was interested in it.
I: Dr. [PER prof] and I and [TA], also, your head TA took 341 together last year, I think. Last year or the semester before, so we were in cognitive.
S: Oh.
I: So, if you're going to stay a psych major, you're probably gonna have to take that.
S: Yeah. I'm gonna have to start taking psych next semester, this semester I was like… let me just see, I didn't know how hard physics was going to be. So I took… this was my easiest semester.
I: Oh, it is?
S: Yeah.
I: How is this class going so far?
S: I was comparing it… I was worried it was gonna be on the level of orgo. I mean, this class is a lot of work…
I: Uh huh.
S: but I think conceptually I understand it better than orgo, so…
I: My impression of orgo was that it required a lot of memorization, but I don't know anything about it, because I never took it. All I had to listen to were my floormates at the time
S: uh huh
I: some of them were chem. majors and they all had to take it, so I had to hear them complain. It wasn't anything objective.
S: See, I'm horrible at memorizing, like, the whole Dr. [PER prof] way of understanding the big picture and the logic
I: Mmmhmm
S: is more the way I think, so orgo threw me for a loop, and in those semesters, I was taking 19 credits, so this semester, I'm taking 14, so that I was leaving myself more time.
I: We have a lot of premeds in this class
S: Yeah
I: People taking biology… a lot of people take cellular biology and physiology classes
S: Biochem
I: And biochem at the same time as this course
S: Yeah, I know a lot of…
I: So they'll be the opposite, right? They'll have gotten used to those classes and then physics will throw them for a loop.

S: Yeah, they hate it. I know, I've heard a lot of people, because all my friends are premed, and they're all like "I can't take it!" (whispered)
I: You want sort of a consistent message from your professors, huh?
S: Yeah. I asked if the answer was right or not, and you don't wanna be asked "well, what do you think?"
I: Well, it's our job to do that.
S: Yeah, no, I know, I'm just saying it makes a lot of people… drives 'em crazy.

Interesting background note

I: I would apologize, but I'm not sorry (laughs). Did you have physics before?
S: I had it freshman year of high school, that was it.
I: Freshman year?
S: My school did like a pilot program where, like, there was not an honors science offered for freshmen
I: uhhuh
S: So they offered honors physics for freshmen.
I: You took it as a freshman?
S: Yeah.
I: Was that the only physics you had?
S: Yeah.
I: That's kind of interesting. There are people out there that really advocate doing physics… teaching it before some of the other ones like chemistry or bio… not necessarily wait til the end. I mean, do you remember anything about that class? Did you get anything out of it?
S: I mean, I remember learning vectors, I remember that.
I: Mmmhmm
S: But otherwise? Like, I remember the projects we did, like, we had to build boats and figure out surface area and stuff like that, but I more remember the building the boat, and not the physics aspect of it.
I: Oh. So, what was the purpose of making these boats?
S: Well, we had to build them, she just gave us paper and little pieces of wood, and we had to fit in them, and we had to paddle them and everything, so we had to figure out the proper surface area so that it would hold our weight, and then
I: You had to get in it?
S: We had to get in the boat in a pool, and paddle it all the way across the pool and back, and we weren't allowed to use nails or anything like that. We just could use glue, and that was it.
I: Oh.
S: And so we had to figure out the tension of the paper, and all that kind of stuff, but as far as doing all those calculations, I don't remember any of that. I just remember building the boat.
I: Did you enjoy it?
S: Oh yeah, we had a great time! I loved the boat project, that was great, and our boat did wonders.
I: OK. Uh, that's kinda neat. Myself and everyone else I've interviewed about this, and all my friends I know, they do the standard thing… you take one or two years in 11th or 12th grade, and we don't do something like that. Was it a special sort of science-oriented school?
S: Yeah. I went to Paint Branch. I don't know… are you from around here?
I: I'm not.
S: In the last few years, I guess… the last… three years ago, they changed… it's Montgomery County, they call it the Northeast Consortium
I: uhhuh
S: And it's Paint Branch, Springbrook, and Blake, which is a brand new high school, and each school has a specialization, and Paint Branch was specializing in science and media, one was arts, and one was more like business and computers.
I: But they're public schools?
S: Yeah, but if you live in the area of any of the three schools, then you can pick which of the three you want to go to.

I: But you have to arrange your own transportation?
S: No, the buses come and get you.
I: Oh really?
S: Yeah. You might have to get on the bus at 6:00 compared to 6:30 if you want to go to the one further away.
I: Understood.
S: But the buses still do come and get you no matter which one you pick.
I: Uh, that's kind of nice of them.
S: So you can have specializations… but my freshman year, we weren't in the specialization yet, so the physics was just something she wanted to do.

Expertise

I: I got you. Outside of background, then, you can answer this question any way you want. How do you know if someone is an expert at something?
S: Um… I guess either their credentials if you have access to that…
I: Uh huh
S: or more if what they're saying seems like they really know what they're talking about… like if you… if someone sits down and talks about something, and it doesn't seem like it all works out, you're not gonna assume that they're an expert.
I: So it has to make sense to you?
S: Yeah.
I: Credential wise, what is acceptable?
S: (laugh) I… training or experience in the field, or their education in that area.
I: All right, often times, they won't come out and say it.
S: Yeah, I'm saying if you have access to that somehow, like if you're looking at their resume.
I: Let's say it's just a talking head on TV talking to a news reporter or something, then use the other definition you were saying.
S: Well, I mean, they'll probably put, like, "expert" underneath, but to really understand whether that's right or not, I would have to say based on what they're saying, whether it seems like they really know what they're talking about.
I: OK, ok. What do you… have you ever seen, on TV or anyplace else in your personal life, a case where you've got two experts disagreeing on something?
S: Yeah, I mean, they put that on TV for debates and stuff.
I: Like, you mean, political debates?
S: Yeah, or, I mean… I can't think of anything specific, but I know they always'll bring… like court cases. Each side will bring in their own expert to… [ok] claim something different.
I: So, you've got two experts, and presumably they're both credentialed, and they've gotten a lot of practice doing the sort of thing they do there, they're used to trying to talk to you so that you follow what they're saying. What do you do when two of them disagree?
S: Personally? Like, what would I decide?
I: Yeah.
S: I guess it would just be what makes… you can be an expert, but then you can look at the data or whatever you're looking at in two different ways and come to different conclusions or the same conclusion, so I guess it could be whatever followed more along my lines of thinking, I would have an easier time believing what they were saying.
I: OK, all right. I think I followed what you were saying. You were earlier talking about how this class is different from the other classes you've had: orgo…
S: Gen chem…
I: Yeah… did you have to take p-chem?
S: No, we don't have to (laughs), and I don't have to take biochem.
I: OK. And it's different because there's an emphasis on understanding things, was I getting that right?
S: Yep.
I: So, you say that, but what do you mean? How do you know if you've understood something?
S: All those tutorials about explaining, like, why you were wrong, and, you know, like… looking at

your mistakes and figuring out what it is you did wrong and, you know, taking what you've learned but not plugging it into an equation but applying it in sort of a logical manner.
I: OK. That's what the *tutorial* does.
S: Uh huh
I: So let's say you go through a couple of these, and one of your friends comes up to you and asks, "do you understand Newton's third law?"
S: Uh huh
I: All right. What determines how you'll respond to that?
S: If I feel confident in explaining it to them, like, if I have the capability to help *them* understand [ah] then I can prove that I've understood.
I: Right. So, we were talking about understanding something, that if you…
S: If I feel confident in being able to explain it to someone else, and that they would understand.

FCI questions

I: Now we can talk about the specific thing.
S: OK.
I: This was the test we gave you.
S: Uh huh
I: Do you remember that?
S: She put it up on the board.
I: She did?
S: Yeah.
I: You didn't…
S: We didn't get papers.
I: Huh. Well, you were supposed to get papers.
S: Oh, but we didn't.
I: I guess it doesn't really matter that much. Well, first of all, I mean, you understand what the instructions are, right? You were asked to circle one and square the other [yeah] that a scientist would give. First off, did it make sense that we were asking you to do that? Did it seem like a reasonable task to give? Normally, the survey is just given out, and, you know, you do it on a bubble sheet, and that's scored and that's it.
S: I mean…
I: So this is a different kind of task
S: It was confusing in a lot of them, because if you're looking for the *right* answer…
I: Mmmhmm.
S: You know, what you believe, then you're gonna assume that the scientist is gonna give a right answer too. So, if you're really confident in your answer, it seems sometimes repetitive.
I: So, by "belief", when you say you put an answer you believe, that's the answer you think is gonna be the right answer?
S: Yeah.
I: OK. And some of the time, the scientist would say the same thing, you think?
S: Yeah.
I: You ended up doing that a lot.
S: Yeah.
I: But there are some cases where that didn't happen, and, so we can look at them. If you've changed your answer by now
S: Uh huh
I: We can talk about that, you can say "all right, I don't think I would do this anymore, if I had to do this again, I would change it."
S: OK.
I: So, I don't know, let's just look at a couple.

N3

I: A truck collides head on with a small compact car, so during the collision… what's what?

S: Well, now, after having the class and the tutorials and stuff [OK], I would go with this one.
I: You mean, you'd go with it as in you'd circle it?
S: Yes.
I: And you would square it too?
S: Yes.
I: OK, but you just squared it here.
S: Because I… from physics and stuff I'd heard before, you know, you hear about Newton's third [uh huh], but at the same time, the whole… like, our raw intuition of what's gonna happen didn't seem to agree with it, so, I could see why a scientist would say that, but as far as *my* understanding at that point, I couldn't tell you why that was… why that one would make sense.
I: OK. Now, when… you did a tutorial on this, right?
S: Yeah.
I: Now, the first question was, you have a truck ramming into a car… was exactly the same kind of thing. [uh huh] Did you or your whole group predict that one of the forces would be bigger than the other?
S: Uh huh.
I: Basically going along with this (points to one of the answer choices) [yeah] the truck exerts more? Ok. And you all saw that, right?
S: Yeah, we all went through it.
I: Then you saw the demonstration that they were the same.
S: Oh yeah… the springs…
I: Was it worrisome to you that there was a difference between the two?
S: I mean, at first, it didn't make sense, when we were all trying to figure out how to, you know, explain it to ourselves and make it make sense in our own head when the truck's so much bigger than everything else, but once we worked through the problems and used the equations to see it and realized that we need to look at force and the change in velocity as completely separate things…
I: OK. So, just looking back on this, you kind of picked choice A because…
S: My raw intuition said that's the one that made sense to me.

Falling balls question

I: All right. Let me see. Another kind of similar one where you may have changed your mind. Check out number one. If two metal balls are the same size but one weighs twice as much, so one is denser metal, or something, the balls are dropped from the roof of a single story building, so the time it takes the ball to reach the ground below… what do you think?
S: Well, now I would circle… C again, and I'd square it.
I: OK, you've already squared C, but you'd change your circle to C?
S: Yeah.
I: All right, so what about choice D? Can you think about anything in choice D that would have been appealing to you at the time before you saw the…
S: Well, just thinking, in extreme terms of the whole idea of a feather and a brick, the heavier thing falls faster.
I: OK.
S: So…
I: You've seen a feather fall slower than a brick? [yeah] well, not necessarily those two objects, but something like it? [yeah] All right.
S: And so, my common sense said the heavier one's gonna fall faster.
I: Right. OK. (looks through test). Some of these questions here, I'm not gonna go through this whole thing, we've only got another 5-10 minutes or so before I'm gonna quit on this, but some of these next couple, you only gave a circle.
S: Yeah, I think I just forgot.
I: That may be the case.
S: Because we didn't have this either, and so we were just going through it.
I: Yeah, that may be the case, that's fine. I mean, I account for that in my own way. But I like to talk about these in the interview because these involve motions you haven't seen in class yet [uh huh], and

he's gonna do a demonstration on this in a couple of weeks, but he hasn't done it yet, so you haven't seen it. Maybe I'll just ask you this… 5. And you can do it right now however you want.

#5, circular motion

I: You have a ball rolling around a track. This is a top view, right, so, it's like the track is sitting here.
S: OK.
I: And it goes from P to Q to R, and at point Q here, you have to pick which forces are acting on it out of those four, so which ones would you pick?
S: Gravity.
I: Uh huh.
S: (pause) and… a force in the direction of motion.
I: OK.
S: But that's it.
I: So you'd circle that one?
S: Yeah (*editor's note, on the test, she circled E, those two forces plus a force from O to q. Nothing was squared.)*
I: OK, would your answer be any different if you were to, say, predict what I would…
S: I don't understand enough about the force exerting from O to q and q to O to know whether you'd say it or not, you know what I mean? I don't feel like I understand it well enough to… [right] to even think about it. I think that's maybe why I didn't circle a scientist's answer, is cause I wasn't even really sure what that was to know whether it's I would think a scientist would say.
I: OK, you circled an answer initially an answer including one of those forces.
S: Yeah.
I: So was there anything appealing about that one? Is there anything appealing about it to you right now?
S: Well, it seems like if the ball is moving this way, and the motion is going this way, that there would be some, like, I don't know, like the whole… when you're spinning in a circle and things, you know what I mean, like in the rides where stuff doesn't move out, it seems like there's a force pushing back towards the wall.
I: So there'll be *something*.
S: So there'd be something [OK], so it'd seem like it would be…

#6

I: Gotcha. All right, now, this one here doesn't require, 6, doesn't require any specific kind of explanations, and you didn't square this one either. So, it leaves at R, and you have to predict which of those paths it would take. So, do you still believe A?
S: No, I think I'd go with B.
I: You think you'd go with B? All right. Um, so you'd circle B now?
S: Yeah.
I: All right. Why do you like B?
S: Just, well, cause once it leaves here, there's none of these forces acting on it to make it go in this direction anymore. So the whole if it was already going straight, like which it is going to try and go, and nothing else acts on it, it's gonna keep going straight.
I: Keep going straight, OK. What was appealing about choice A before?
S: I was just thinking that if it was already going in a circle, it might have… the motion was already circular, it might just keep going.
I: It might keep doing that. OK. All right, so that sounds fine. So (pause), let's see. What do you think about this next one?

#7

I: 7, with the… whirling a ball around your head.
S: That…

I: The string breaks at point P, and you have to pick a path.
S: I would be torn between B and C (*ed. Note: she circled B and squared nothing)*
I: B and C. OK. Why would you like B?
S: I just, I don't know, I guess the whole common sense thing, if it breaks here, you're… it's already being swung in this direction, so it's just gonna keep going straight.
I: OK.
S: But based like on… this one, no, I think I still like B.
I: OK. Not C then?
S: I think I like B.
I: All right, that's fine. Let's see if I can find some others that you haven't necessarily seen yet. (pause) I think some… some of these other questions are a lot… that you've done this difference, are a lot like #4
S: Where I've already learned it now.
I: So I don't need to talk about those again. Um, make this the last one.

#11

I: 11. You have a hockey puck that's sliding on something and it's not feeling any friction, I think is what it says… yeah, frictionless. You kick it at B, you were supposed to pick which path it takes, but I'm interested in this question, so you choose a path in question 8 which it goes after you kick it.
S: OK.
I: What are the forces acting on it after it gets the kick?
(pause)
S: Um… downward force of gravity [mmmhmm], and the force of the ice touching the hockey puck [anything else?], so B. After it's been kicked?
I: Yes.
S: No.
I: So that's D.
S: Yeah.
I: You would circle that?
S: Yeah.
I: If I gave you this now, would you square anything else?
S: No, I'd square the same thing.
I: OK. Can we just talk about what was going on here possibly, before? You had circled only gravity.
S: Yeah. Well, I'm… now I'm thinking, like, in Dr. [PER prof]'s thing of thinking about as the hockey puck and everything that's touching you [uh huh], but before when it said frictionless, I thought the ice didn't really matter.
I: Oh, OK.
S: So that's why I just said gravity before.
I: So, maybe the scientist answer then…
S: would seem more complicated and involve things I wasn't sure about, so… that's why I picked it.
I: So this one involves things… (referring to D)
S: I wasn't sure about.
I: Like what? Like this upward force and the horizontal force?
S: Yeah, I wasn't sure about those.
I: For choice C?
S: Yeah. I was, so, it sounds complicated, and scientists talk complicated, so…
I: You know, I should have expected it, but I think you're maybe the fourth person I've talked to, and the third one that's said exactly something like that (laughs), so this is really something that's coming up a lot. Uh…
S: It is true, if you listen to a scientist talk, a lot of times, you don't understand everything, and so if I didn't understand everything in the answer, it seemed like a plausible scientist explanation.
I: OK. Is that at all similar… you did this sort of different thing… on every question where you had two people exerting forces on each other [mmmhmm], and you had to compare them, um… on this question where a truck collides with a car, and on this question where a big person pushes off on a small person on rolly-chairs. There's another one where you have a car pushing the truck, and the car

is pushing the truck and the two things are speeding up… [mmmhmm]. You have a different answer for both of those. Is that the same kind of thing?
S: Yeah, just… I can't… I know that Newton's Laws exist, but I didn't understand them well enough to explain them and make it make sense to me [uh huh], so since I knew they existed and a scientist would know Newton's laws, I picked the answer I felt fit more Newton's laws [ok] for the scientist, but for me, I picked the one that I just thought made common sense.
I: All right, all right. I guess this is sort of an 'after…' what's the word I'm… sort of a debriefing kind of question on the tutorial you saw, right? N3?
S: Mmmhmm.
I: Does that make more sense now?
S: Yeah, definitely, the tutorial sort of put it all into perspective.
I: So that was helpful for you?
S: Yeah, definitely.
I: OK. Cool. I'm glad to hear it then. (laughs). I think that's about it. Was there anything else, I mean, was there anything about the test you wanna know?
S: Uh, I guess not. I just want to forget it for now.
I: Oh, you do?
S: Enjoy my weekend and deal with it on Monday. (I discusses makeup/regrade info)

Emily's interview

Interview: "Emily" for FCI survey
Interviewer: Tim McCaskey
Done on 10.15.03

Prelude

I: I went around to all of the sections, and we have to give some sort of incentive for doing this sort of thing [right], and I can't give points, but we have grant money that… our group has done all sorts of interviews, so part of the grant money that we write goes into, you know, paying for interview subjects, paying for things like audiotapes, videotapes, cameras, all of that wonderful stuff, and so we have the money for that, and if ever we (ed note: grad students) need to spend something out of pocket, we always get it back, but people don't know that. I may have gone up there saying, "I can't give you points, so I have to pay you, so you get 5 bucks," so they think, "oh, man, he probably only makes 4.25 an hour." (laughs).
S: What they do with negative money.
I: So not only… not only are we taking his money away, but he's gonna be poor, so none of us better sign up. I think that's roughly what happened.
S: Yeah.
I: So, as I promised when I first came in, this is the survey that this thing is about.
S: OK.
I: Uh, we'll get into the specifics later [OK]. I have a couple of specific items on this in mind, and that's why I'm glad you came in when you did, because if we waited another week or two, he'd have covered [same time: it would change] he'd have covered them in class already [OK]. Now, maybe your answers have changed, and if that's so, fine, we'll talk about it [OK], but the sad thing is, in the first two weeks of class, he covered over half of this.
S: A lot of it.
I: So it's hard to, it's hard to stay…
S: I'll play dumb, I dunno.
I: No, no. I mean, right… I found a couple of things on here that we haven't addressed yet, so [OK], and even if there are any questions on here that I'm gonna go back to that you have covered, then certainly, yeah, we'll talk about it if you've changed your mind, why, and what could have been going on before.
S: OK.

General stuff

I: Some general stuff first, though. What year are you?
S: A junior.
I: What are you majoring in?
S: Neurobiology and physiology.
I: Is that for premed or something else?
S: Yeah, it's premed.
I: You're a premed, so, you're taking the course to… because it's required?
S: Satisfy a requirement.
I: OK. Any other reason, other than to satisfy…
S: Prepare me for the MCATs.
I: OK, cause they're… this stuff is on the MCAT.
S: Mmmhmm.
I: OK, that's true. Did you have physics in high school?
S: One year.
I: One year. Junior or senior year?
S: Senior year.
I: Senior, ok. Did you get a lot out of that?
S: No, not so much.
I: Why not?
S: Our teacher was just beginning, he was just out of, I guess, college or getting his masters in teaching, and it was kinda like his first year with us [uh huh], so he was getting used to teaching, and we did a lot of just plugging into equations, and even though, yes, that helped me, I understand how to use the, I guess, utilize the equations, I don't really understand… I didn't ever understand the concepts we were doing, pretty much.
I: OK, and you think that's just a function of him being a new teacher?
S: I dunno, or, no… but how he chose to teach the class it was equation based rather than concepts, really learning about things, so… maybe not just a function of him being a new teacher, but…
I: Right, I mean, a lot of people go through that same experience in all their physics classes in high school and college, I mean, I was a secondary ed major myself for a while, and although we're not encouraged to do straight lectures with lots of equations, that's the sort of traditional model for teaching physics classes, and maybe that's what he…
S: Yeah.
I: So, wait, in what sense was it useful, then?
S: Um, I mean, I basically, I got a good, I guess basis or preview, if you will to physics, because I had never been exposed before, I was pretty much bio and chemistry.
I: Do you think that exposure has helped you in our class?
S: Not so much, I think because I had it three years ago, and because I didn't practice it so much, it seems like it was just plugging in equations and never really [OK] I kinda lost what I learned.
I: So you forgot some of it [yeah] and just haven't used it?
S: Yeah.
I: Yeah, ok. All right. I've got a little bit of a cold I think. I can see how that happens. If there's something that doesn't affect you in some deep conceptual way, and you don't use it for a while, it's easy to forget. Physics class-independent question, next, then. How do you (pause – getting sick)
I: How do you judge if someone is an expert at something? How can you tell?
S: If they're able to explain to me… wait, in the teaching sense, are they an expert?
I: Well…
S: Are they teaching me?
I: In whatever sense you want.
S: First of all, if they know a lot of that subject, and they're accurate in what they know [ok], and also if they can explain to me what's going on, I think they're an expert because they know it so well that they can kind of take different angles at it [ok] and help me see… get a general understanding of the topic.

I: OK. That's perfectly valid, it's the kind of answer I've heard a lot to that. Have you ever seen experts disagreeing?
S: Yeah.
I: Give an example?
S: (pause) Let's see. Right off the top of my head… I guess in biology, there's different, like, let's see, if there's some sort of theory put down, and you think that they're an expert, and a couple years later, a different experiment is done to kind of nullify that experiment saying no, this is what's really going on… at one point you would have thought he was an expert because…
I: So, let me get this straight, the person that came out with the first result [mmmhmm] is discreted later [yeah?], is the first person no longer an expert?
S: Um… no, they… in their field I wouldn't call them not an expert, but maybe in that specific experiment, they are no longer an expert because the results, I guess, didn't hold up in the long run.
(is someone coming in? – I… [TA] comes in and interrupts briefly)

I: So, how is this discrediting process done? I mean, you say you have two experts disagreeing, suppose another person comes around and disagrees with the first result from a while ago, for whatever reason. How do you decide that that's right and the first one wasn't right?
S: I guess the more evidence, the more facts that you can support the experiment, in this case, since we're talking about an experiment, if they hold up in the long one, then I'm gonna be more prone to believing the person that has the better data, I guess.
I: So you're making a judgement about whatever data they give you?
S: Yes, and if they can apply, if their discussion on the results holds up, I mean, I'm not gonna just accept data, whatever they say…
I: All right. If you didn't come up with one off the top of your head, I mean, you did for biology, I'm glad we were able to talk about that… the one I would have suggested was you have experts or so called experts in politics disagreeing on things. How do you decide… what do you do when two experts in that field disagree? I'm just asking this because it's come up in a lot of previous discussion.
S: Um, let's see… like a certain topic?
I: Um, do you want a specific one? There were a lot of experts on TV disagreeing whether the war in Iraq…
S: Was OK or not? OK. Um, I guess you just have to, um… I'm not saying… I don't think either one was nullified in their expertise [uh huh], but what I guess I would look for… facts from both and then kind of decide for myself which one I agree with. But I think they're both experts.
I: OK, it's that last statement you made there that I'm kind of interested in, you decide which one you agree with.
S: Yes.
I: What's that process like?
S: OK, well, you first, first of all have to look on both sides, you have to get facts from both angles, and then you have to make an informed decision, so you kind of have to weigh one against the other and decide which one that you think pertains best to you and your beliefs, I guess.
I: Kind of like a matching process then? [mmmhmm] All right. How is the class going? Our specific course.

Class question

S: Um, so far, I guess, so good. At first, I was a little thrown off, because I expected it to be equation based.
I: Like your first physics class?
S: Uh huh. And then I was wondering why we were doing all of this kind of concept reconciling my intuition versus that, and it was kind of hard for me [ok] because my intuition wasn't, it's kind of never what physics said, so it took a lot of reconciling.
I: What do you mean?
S: What I initially thought was usually not physics.
I: Like the car/truck collision?
S: Yes.

I: You had the truck force being bigger?
S: Yeah.
I: When you were pulling Timmy up from the well, you had the rope force being bigger too?
S: Yes. (laughs)
I: Do you feel you've gotten some of the concepts down?
S: Oh yeah.

Understanding question

I: How do you know if you've understood something, though? I mean, how do you judge that?
S: Well, like, when I was studying, I guess, for the test, I kind of… if I understood it, I was in a group study, and I could explain to other people what was going on, and I was explaining… like, because if they didn't get it one way, then I had to adjust how I was explaining it.
I: Has that worked?
S: Yes.
I: And if you can do that… then?
S: I'm pretty sure that I know the concept.
I: OK, ok, I got you. That ends the general questions, I had to get that out of the way. (editorializes on why general questions are needed)

(other quote): Yeah, I was gonna say, with understanding, like, if I can apply a concept to more than one type of problem, also. I know that I kind of get what's going on.

FCI questions

I: You remember this task we gave you?
S: Yeah.
I: This survey, right? These were the instructions, do you remember?
S: The one I believe and then what scientists… yeah.
I: Normally when this is given out, right, this is just printed off by the hundreds, handed out to a big lecture class with bubble sheets, and they just answer it, whatever. It's not done like this. Did it make sense that we were asking you to do it this way?
S: Um, in some questions, yes, and in some questions no, because…
I: OK
S: If it was an answer I really believed [uhhuh], then I didn't want to contradict myself and say "well, no, a scientist would really say this", so I wanted to circle and square the same answer.
I: Those were the ones you were the most sure about?
S: Yeah.
I: Does that sound right?

Alarming insight on circle/square

S: Yes. And then for the ones where my circle and square were on different choices [uhhuh] I thought maybe it was just my intuition based answer, so then a scientist might say something different because it wouldn't… they would be basing their answer on… facts, I guess.
I: So, would you say that the questions you did this different thing on [mmmhmm] is an indicator of your confidence or your… yeah, your confidence in your intuition, I guess?
S: Yeah, or lack of confidence in my physics answer.
I: Lack of confidence in your physics answer, now, are you saying that your physics answer on one that you had a difference would be the one you circled?

S: The right answer? I usually put the square around… what I thought was the… see, I dunno, I thought you guys wanted to see, like, a difference between what I thought and what a scientist would think.
I: Right.
S: So, a lot of the times, I didn't circle and square the same answer. I put down… just reading the question without thinking so much about it, I kinda just circled what I thought intuitively, and then I went back and tried to think about it and thought, "well, maybe a scientist would say this."
I: So, so, I mean, we'll go over… let me actually find one where you, uh, right.

#6

I: #6, here, there's a ball in a channel, and it comes out here, and you're supposed to pick which direction it goes
S: Uh huh
I: Now you marked circle and square around the same thing.
S: Uh huh
I: Why is that?
S: Because I really didn't think that there was another path. I really believed that my answer was correct.
I: Was this an intuitive answer, though, that you were giving?
S: No, not really. Because, well… (pause) I'm thinking about… well, yeah, I guess.
I: OK. But you were just more sure of it?
S: Yes.
I: Yeah. You said on some of them it makes sense that we asked you to do that. Circling and squaring the same one was supposed to be a valid option, and a lot of people did that for every question.
S: Oh (laughs).
I: (looks around)
S: The things I felt more confident about, I definitely circled and squared the same answer. The things I was unsure about…
I: So, like this one, uh, #20…

#20

I: You're tracking blocks at 20 second intervals, um, what are the accelerations? You circled and squared "the acceleration of A equals the acceleration of B and both of em are zero."
S: Mmm-hmm.
I: Do you still believe that's right?
S: Yeah, because… the change in the… their paths are not differing.
I: OK, so it's consistent. [Yeah] Would you consider that an intuitive answer, then?
S: Yeah.
I: Does that make sense to you?
S: (snicker)
I: I'm just trying to make clear what the distinction is, and you can tell me if I have this right [OK.]. You circled sort of which ever one made sense to you [mmmhmm], and if you seemed relatively sure of that…
S: I squared it too.
I: But if you were not sure of it, then, well, let's see...
S: If I was between two answers, I kind of… I'd probably circle and square different choice.
I: Right, so let's look at one. Here's an example, you have a ball on a string and you're swinging it horizontally, so this is a top view.
S: OK.

#7

I: You're swinging it around, and at point P, the string breaks, so which path does it follow? You can look at the answer you give. I guess my first question's gonna be, would you still say that?
S: The circled one or the square one?
I: Well, both. Do you still think that you would… you would mark it this way?
S: No, I think I'd circle and square the same one.
I: Which one?
S: I would say in this… it's B.
I: B. OK. This might be hard, cause it's been a couple of weeks, but do you remember or can you still think of anything attractive about answer C that would lead you to…
S: I think I said C because… let me think here (pause)… I don't know why I would ever circle that, because it breaks outward? I'm assuming if it broke here… I'm not really sure why I squared C.
I: OK, that's all right.
S: I'm sorry.
I: No, it's…
S: It seems… or maybe, I thought it was losing, when it broke, it came to an absolute stop and just kept going outward. I dunno, that's not a very good answer, I don't really know why I chose C.
I: All right, um…
S: (laughs) I'm not helping so much.
I: Oh, no, that's fine. If this came up, if you can't justify now why you picked it, I need to know. Sometimes there's a reason and sometimes there isn't. I'm just trying to pick out some questions that haven't been done yet…
S: OK.
I: Sadly, there aren't many. I guess this is another one that you haven't explicitly talked about in class yet.
S: OK.
I: It's the same problem that you answered in 6. It's the ball traveling along this channel, and the four forces are gravity, a force exerted by the channel from q to O, toward the center of the circle, a force pointing from O to q going outward
S: OK.
I: and a force in the direction of motion, and you're supposed to pick which of those is acting at this point little q here.
S: OK, and, it says… forces are… (mumbles), and I wrote (long pause). So, gravity, I said, well, 1, gravity is in every one, so obviously. Whatever. So, then, a force exerted by the channel pointing from q to O [mmmhmm]. I said that was included.
I: Do you still believe that?
S: Um… see, I think my problem with this, and this is why I circled, um, two different things [uhhuh] I was having a difficulty distinguishing the difference between q to O and O to q. I wasn't sure where the force would be exerting. I guess thinking about it now, I'm not really sure, O doesn't seem like, it's just the center of it [yeah], um, and it seems like it wouldn't have a force on Q, like, Q is the thing that was moving, if I was looking at Q itself [oh] as the object itself, I might be looking q to O, but I think that's where I was having some discrepancy.
I: OK, the forces from q to O and O to q are… I mean, the only thing touching the ball on the sides is
S: the channel itself, right.
I: So, I guess the question, then, would be: do you think the channel is pushing you in towards the center, or something is pushing you out, or whatever it is?
S: I would think someone, something is pushing me out, because if these two channels weren't there to direct my path, I would be… say it was only the inside part, I wouldn't be able to stay in a circular path, I'd be going away from O.
I: Oh, OK, so (pause) so something is pushing you out, then.
S: But, yeah… but, because I am inside this channel [uhhuh], it's, uh, the pushes are evening out and keeping me within its…
I: There are two pushes?
S: One from the inside channel, one from the outside.
I: Oh.
S: But, the channel is not an option here.
I: Yeah it is. This choice 2, a force exerted by the channel from q to O.

S: Oh.
I: That's the option of the channel pushing in.
S: Oh, so…
I: And you could easily see 4 as the channel pushing out.
S: Yeah.
I: So, do those both exist?
S: Unfortunately. I would probably say yes, but that's not an option.
I: So is there still a conflict for you, then, between choices D and E.
S: Yes.
I: OK. Is there any reason you think that a scientist or an expert or physics professor or whatever would…
S: Would say 4 instead of 2?
I: Yes. Would say 4 instead of 2.
(pause)
S: I think I said that because I was thinking that a scientist kind of looks at the entire system, and that maybe that if my answer, if I was talking about 2, the exerted by the channel pointing from q to O, I'm thinking more in terms of just Q, and that's an outside thing could be going on, so O has a force on q, and maybe that's what a scientist would be looking at. Um… like, do you see what I'm saying, or no, not really?
I: Um (pause), I think so, but rather than try to put words in your mouth, could you give that another crack?
S: OK, um… I think when I was looking at what the scientist view was, when I just initially just wanted to put down an answer, put my answer down [uh huh], I was looking at q to O because I was looking in terms of q, like, that was the object at hand, so that's what I was thinking. So, I kind of just put that down. But if I was thinking about the scientist… a part of me wanted to think that they'd be looking at the system in its entirety, and that O would have some influence on q.
I: O would have some influence on q.
S: So, there would be a force from O to q.
I: So, treating O like an object?
S: Yeah, well, not… maybe, yeah, some sort of… I know it's not a tangible object, but maybe there was some force that'd be going on q in that, from that direction.
I: Maybe there's some…
S: Something…
I: Something…
S: there that I wasn't, I'm not aware of
I: accounting for… Is it worrisome to you at all that this conflict exists.
S: Yeah. (laughs)
I: So, what would it take? Do you think… do you think you could argue, you could effectively argue your case for choice D?
S: Um, I would think so. I think that from what… how this course has been going so far, how I've been reconciling, I guess, these differences [uhhuh], definitely through the tutorials, because I'm seeing it in an experience that I can relate to, because just like putting letters on paper, it's… I kinda I guess get confused with what is really going on. And also by experiments he's done in class and things like that, so… I might be able to argue my points now, but I don't know… if they'd be the correct points to argue.
I: You're not sure if they're right?
S: Yeah.
I: So, conversely, do you think there's some way that an expert through a tutorial or lecture [yeah] could convince you of E? OK. You'll be dealing with this pretty soon in a couple of weeks, to work it out. [OK.] It's a quick thing.
S: He's like (referring to me), "it's really easy, you're just…" Sometimes I really just feel dumb in physics.
I: All right. Let me help you feel a little bit less dumb.
S: (laughs)
I: Choice… actually… a force in the direction of motion. [uhhuh] Do you still believe that? That there's a force in the direction of motion?

S: (pointing) That way?
I: The direction of motion at this instant is going…
S: toward…
I: toward me, I guess.
S: Right.
I: Take a look at that.
(interruption)
S: OK, well, force… I would say yeah.
I: That there is one there.
S: Yes.
I: Well, let me address two things. One of them, and this should make you feel a little less dumb about it… the force 2, by the channel from q to O is the one that's there.
S: Oh…
I: Going in. And the way you'll see this later, is you just draw little velocity arrows before and after, you take their difference and you see what direction it points, that tells you the way the net force is. The force in the direction of motion, we were hoping… this is completely different context, so I can understand why the confusion would come up, but it's just like the Timmy in the well thing. Do you need a force to be going at constant speed in the direction of motion? A net force?
S: You're not accelerating, you're just going, so no.
I: Right. This thing is accelerating, and we'll talk about that acceleration in a bit, but it's an acceleration not in the sense that you're speeding up, but just changing direction.
S: Oh.
I: A force in the direction of motion would speed you up in a circular path.
S: Ohhh…
I: So your intuition about what this force, what direction this force pointed… is right.
S: OK.
I: So, if you think there's this expert answer that you just can't account for, you're just getting a better sense in the tutorials… what can you make sense of and what can't you. OK?
S: OK.
I: So, I don't mean for these things to make people feel better about [S: laughs]
S: thanks

N3

I: Hey, I'm here to help. All right. So, there were three or four questions about Newton's third law here.
S: OK.
I: Here, actually, let me… is there one that's more like our tutorial? (looks) I don't care. Pick any one. A car is pushing a truck because this truck is broken down and the car pushes it.
S: OK.
I: So, the car is still pushing the truck, if you're speeding up to get to cruising speed, look at those options for the forces… this is the last question, so… I just wanted to ask one of these. I know you've already seen the material.
S: Well (pause) I would say A.
I: You would say A? If you were to do this now, you would circle and square A?
S: Yes.
I: OK, why is that?
S: Um, because at this point, I've learned that the forces… um… on the force of the car to the truck and the force of the truck to the car [ok] are going to be opposite and equal. Equal and opposite, or whatever.
I: OK. OK, so…
S: Because it's an individual force… I guess when I was answering it, what I wanted to say in order for the car to push that
I: Uh huh
S: It would have to be more. I said that because, obviously you have this little tiny thing trying to push this big thing.

I: So it's gotta win somehow?
S: Yeah.
I: OK.
S: And that was the way I was thinking it wins, but, um, in this case, acceleration is going to be different.
I: Well, the acceleration is there… right? The car and the truck are accelerating together.
S: Right.
I: OK.
S: Oh, so they have the same acceleration?
I: Well, they're touching, so it's like the pushing the blocks problem in tutorial?
S: Yeah.
I: OK.
S: So then the forces have to be different on one another.
I: OK. How did you resolve that in tutorial?
S: We went through that… even though different sizes… the truck and the car, different masses, um… those masses times acceleration which would be, I guess, the same, equals your fnet.
I: Wait, that's how you reconciled Newton 3 for the first time, right?
S: Mmmhmm.
I: When the truck was ramming into the car? Yeah. That's how we always convince people that Newton 3 works out. I'm talking about the different situation where you're pushing two blocks together.
S: OK.
I: I mean, you exerted 200 newtons on the left block, and we asked you if the 200 newtons is transmitted…
S: Oh, oh. Was it or not? And we said no, it wasn't transmitted to… incompletely.
I: In that case, though, were the forces that the blocks were exerting on each other, were they the same? A on B and B on A?
S: Yes.
I: OK. How did you know they're the same?
S: Because… there's no acceleration.
I: But there was acceleration, I mean, when you were pushing the blocks, they were accelerating.
S: But they're moving together. So between the two objects… there's… I guess you can say overall acceleration of… if you can treat that as one block, but since they're not… since the block, the small block on the right is not moving away from the bigger block, they're moving together, they have to have the same acceleration.
I: Oh, right, so you know they have the same acceleration.
S: Yeah.
I: Um, I was just wondering… (draws) here's A, and here's B. [yeah] The two forces that are in question here… this is the touching force of B on A, and this is the touching force of A on B [yeah] were those two the same?
S: Yes.
I: Because?
S: Because they're a Newton 3 pair.
I: cause it's a Newton 3 pair.
S: You have the same two… they're on opposite… the forces are on two different objects, but they're two same variables acting on it.
I: Is this car and truck situation any different than the situation where you're pushing these blocks and they're accelerating?
S: No.
I: So you believe that the forces are the same?
S: Yeah.
I: Right… and… I drew these wrong anyway (fixes direction of arrows in board drawing). The reason A is able to accelerate is because we have this big pushing force on it, OK? The car has the same thing.
S: The engine on…

I: Is the engine what makes the car go forward?
S: The wheels on the ground.
I: Right, it's the friction issue, but it's still (laughs) a big forward thing, and the forces will be the same. So, does that make sense to you? Is there any question in your mind now that these forces are equal?
S: You mean, if they are, or if they aren't? No, I think they're equal.
I: You think they are?
S: Yeah.
I: And you believe that, even though it's two different masses and they're accelerating?
S: All right.
I: So, what was attractive about this C choice?
S: Well, it's amount of force… was the car pushes on the truck, so to get that truck even moving, I would think that the force would have to be greater.
I: You already answered that. I'm dumb, I'm sorry.
S: No, that's fine. Hopefully that helped, sorry… you needed to go round and about with me there.
I: Oh no, that's perfectly cool. You had perfectly thoughtful answers to everything I've asked. Some of them I've heard before, but I want to hear a lot of different things which is why I need to give more than one interview.
S: Awesome.
I: I've done 4 before talking to you.
S: There you go, well, good luck with everything.

Jackie's interview

Interview: "Jackie" for FCI survey
Interviewer: Tim McCaskey
Done at 10 AM on 10.2.03

General stuff

I: I'm just gonna start with the general stuff, I kinda have to know where you're coming from. What year are you?
S: A junior.
I: What are you majoring in?
S: General biology
I: OK, so, 121 is required for that?
S: Yeah.
I: OK. Do you think you would have had any reason to take it if the school didn't make you?
S: Uh, no. Well, some of the medical schools still require it.
I: The medical schools… it's on the MCAT, rather?
S: Yeah.
I: Are you pre-med?
S: Yeah.
I: OK, so you're trying to do that. (quotes approx statistics on premeds in the course)
--
I: Had you had physics before coming here?
S: Um, in high school.
I: One year or two?
S: One year.
I: Did you like that class? Did you get a lot out of it? What did you think?
S: Um, that was a while ago. It was a lot more of just plug-and-chug with different equations and formulas and stuff, so we didn't really *learn* a lot about physics, but…

I: Um, I know it was a long time ago, but did you feel you did at the time, or was the structure of the class kind of…?
S: Yeah, I guess at the time I thought I was learning physics.
I: OK. Hm. This class is going OK for you? How do you think this class is going? This interview isn't related to the class at all, I'm just kind of curious.
S: I'm enjoying the class. I'm enjoying his way of teaching it, I like learning why stuff happens, so…
I: OK. So… a question outside the whole range of physics courses. How do you tell if someone is an expert at something? If someone claims to be an expert, how might you judge for yourself?
S: Um… how well they can explain stuff, like, if you give them a situation, if they can explain it well and really seem to know the reasons why stuff goes on.
I: So, part of it… part of it involves a certain ability to explain to people outside their subject?
S: Yeah.
I: Right, OK. So, do you consider teachers in that category, somewhat?
S: Yeah.
I: All right. I'm trying to think which of these is the best to ask… have you ever been in a situation where you've seen two experts disagreeing on something?
S: Yeah.
I: Like what?
S: Like a lot of stuff in government, I mean, you have so many different sides.
I: Political issues? [yeah] OK. So, how do you come to a decision as to which is right when two experts disagree?
S: I guess it's more… with government issues and stuff… with your personal opinion.
I: So you pick whichever…
S: Yeah, if you can…
I: Whichever side agrees more with your personal opinion?
S: Yeah.
I: OK. I don't know your group dynamic, maybe I should, I guess I've seen you, but do you have a lot of disagreements with your other group members when you're doing tutorials?
S: Um, sometimes.
I: OK. Is it a question then of… going with whichever side is your belief?
S: Um… (pause) well, I guess, I mean, in tutorial, we kind of argue it through. Everyone brings up points that maybe I hadn't thought about, so…
I: OK. Would that be applicable in the government situation, or in talking about politics and government, or is that too different?
S: I think it's a little different. A lot of those issues are personal, where physics is kind of your understanding of the concepts.
I: OK, right, right. Now, in the… in this class you've done and in other classes, do you feel you've gained understanding of certain things?
S: Yeah.
I: How do you know when you've understood something? For you… it's different for various people, so how do you know?
S: When I can apply it to stuff… that really goes on, in physics… when I can apply it to a book sitting on a table… when I can apply it to the real world, I guess that's when.
I: Apply it… what do you mean by apply it?
S: Um, just make sense of stuff that happens, I guess.
I: That maybe you weren't able to before?
S: Yeah.
I: OK. That's the general stuff.

Specific FCI stuff.

I: That's the survey you did. You remember the instructions that we gave you for this?
S: One was what I thought, one was what I thought a scientist…
I: A scientist would… right. The circle is the one you thought. The square is the one that scientists said. Now, I've gotten a lot of different responses, actually, some of them unsolicited, when the survey was given out in past years. People answer this question in different ways, but, does it make

sense that we're asking you to do the task in this way? Normally, when the survey's given out by anyone else, they just take it, they do it on a bubble sheet, and that's it, they turn it in. Did it make sense that we were asking you to do this?
S: I guess, kind of. I mean, I know by the end of it I was kind of circling what I thought was right and squaring a technical one. I mean… what I thought scientists would say sounded more technical to me.
I: Oh, ok. Was that toward the end more?
S: Yeah.
I: Oh. So, at the end, was that the basis of picking which one the scientist answer was? You looked for which of the choices…
S: Yeah, it was just hard to choose sometimes. I'm a junior majoring in biology, so I kind of consider myself a scientist, I have good scientific thought, but…
I: Uh-huh.
S: So it's hard to distinguish what I would say from what I think a scientist would say.
I: Do you think it would have made a difference if we had asked what answer you would give and what answer a physicist would give?
S: Maybe.
I: Would that make a difference? Maybe then you'd still look for the…
S: Yeah, the technical sounding…
I: More technical thing. We all talk like dorks, right? I know how it goes. If you've said… did you think this was too long?
S: It was a little long.
I: I think maybe the thing to do, then, is to look at some of the ones from the beginning, I picked out some questions… I picked out especially some questions that I don't think you've talked about in class yet. So maybe we can talk about why you put the stuff you did. Let's look at… if you've talked about it in class, we can mention your experience too, but we can also look back at what you were doing when you filled this in.

(FCI Q.)
I: A stone dropped from the roof of a single story building to the surface of the earth, and you have to describe what it does. Could you look at those choices just to sort of refresh yourself? (long pause)
S: OK.
I: OK. Do you still agree with this?
S: No.
I: Choice D? OK. Which would you pick now?
S: C.
I: You'd pick C: "speeds up because of an almost constant force of gravity acting on it." If you had to mark a square, where would you mark the square now? I would have liked to have done this before you had a lesson on gravity, but…
S: Yeah. Um, I guess still B. It still kinda sounds…
I: What's attractive about B that you would mark that as sort of the "physicist answer"?
S: Well, I know gravity changes with different altitudes. I don't really know the reason behind that, so I guess, since I kind of… a little bit, I kind of tried to make sense out of that little bit I knew.
I: So, given the lesson you've had now, there would be a circle around C and a square around B. Do you think… so, there's a difference. Is it worrisome to you at all that there's a difference between the two answers, or not?
S: What do you mean, worrisome?
I: Um, well, let me put it this way, if you just had this to take as a test that counted for something, which one of those would you mark? If you only had one mark of the pencil…
S: Probably C.
I: Probably C. Would it bother you then, that you had this idea that physicists might say B?
S: I guess… a little bit. (pause) I don't think it would bother me that much. I guess I'm pretty set on C.
I: OK, do you think that you could get an expert in this subject to see where you're coming from writing down C?
S: Yeah.

I: How would you try to do that… say you were talking to your professor, or something, and you were trying to convince him that C was the best answer.
S: Probably use our Newton's laws… if there's a constant force of gravity, there's a constant acceleration, so… the object's going to be speeding up with a constant acceleration.
I: OK, let's see… (pause) Do you not then really believe the story you gave for part B?
S: Yeah, I mean…
I: What's your basis for thinking about gravity in terms of different altitudes?
S: Um,… well, I guess if it's just coming from a single story building, it's not gonna matter. If you're dropping it from the top of a mountain, it might be different.
(I points out that g changes with altitude and there are correct aspects with both.)

I: Have you done… here's a question where you have a ball in a channel, right? And it rolls out the end… you haven't done this demo in class yet, have you?
S: Mmm-mmm. (no)
I: I think that's coming up soon, so this one is a good question to ask. Can you look over, are you familiar with this situation?
S: Number 6?
I: Yeah, number 6.
(pause)
S: Is this… (long pause)
I: So you're looking down at it. OK? So the ball's rolling through this, and it goes off the end. You're gonna… I mean… I'm not gonna give away the answer afterwards, because you're gonna do this later in class, I think, but do you stand by these answers you gave back then… a couple weeks ago?
S: I guess so. I'm kinda torn between the two of them.
I: All right. Let's talk them out. The choice you circled for the one you believe is A, and this is the one where it leaves the track and sort of curves inward. Why might you think it does that?
S: Because that's kind of the path it was following…
I: So it will complete the circle?
S: Yeah.
I: OK. What about C then? Choice C is squared.
S: With like, centripetal force or whatever, it's kind of pushing against the outside, so when it reaches the end, it's gonna keep pushing it outside and kind of...
I: Oh, so you're talking about the force the ball… the ball is pushing on the track, you mean?
S: Yeah, the outside of the track. (inaudible)
I: Oh. I think I see where this is going. So it's like, if I'm pushing on someone, and all of a sudden he moves out of the way, I'll kind of fall forward a little bit in the direction I was pushing.
S: Yeah, well, kinda like if you swing a bucket of water around, the water kind of stays toward the end. If I swung it around, the water is like pushing against the outside, so if somebody released the bottom of the bucket, the water's gonna kind of go outward.
I: Oh, the water would go out? OK, ok. So, here's a case where one inclination is to have it curve in, and another inclination is to have it curve out.
S: Yeah.
I: Is that worrisome that there's a difference, possibly, between the two?
S: Yeah, cause they're really different (laughs).
I: They're really different this time. OK. Do you think… which order should I do this. Your point of view is going like this, that it would complete the circle. Do you think you could convince the rest of your group or possibly your tutorial instructor that the ball would do this?
S: No. (laughs, pause) Um, I mean, like, the object in motion likes to stay in motion, an object going 35 miles per hour wants to stay 35 miles even if something stops… if you turn the car, or whatever. It kinda follows along the same lines… something going in a motion, a circular motion's gonna want to keep going in that motion even after it's… path is discontinued.
I: So, you see the circular motion as being… sort of an application of Newton's first law, that's the one you were quoting, that objects tend to remain in the state of motion they're in.
S: Yeah.
I: And this is in the state of motion that…

S: The track was… yeah.
I: OK. Which of these choices, A or C, do you think you would prefer if you only had one on a test?
S: Well, I mean at this point, probably A, just because I can try and explain it with stuff I already learned. In the case of C, I don't really know how centripetal forces really apply to stuff yet.
I: Ok, so… you haven't seen this yet, but maybe you will down the road. How do you think you'll settle this later?
S: How will I settle it later? (pause) I don't know. I mean, C kind of makes sense because it is still kind of trying to go toward the center, but it curves outward, so it kind of (pause) yeah… I don't know.
I: Just not sure yet?
S: Yeah.
I: OK. So, all right. I think we've touched on the issues there. Let me see if I can find anything else interesting… one that could be good. All right. Here's another one with some forces on it. You have a boy swinging on a rope, this is #18, a boy swinging on a rope, starting at a point higher than point A, so he's already moving right here. You can tell because of the sleek little racing stripes.
S: Yeah.
I: I didn't notice that before, but it's kind of cute. So, the forces are a downward force of gravity, a force by the rope from A to O, a force in the direction of the boy's motion, and a force going from O to A. So… look at these… the choices are 1, 1 and 2, 1 and 3, (1, 2 and 3), and (1, 3, and 4).
S: Ok.
I: OK. So, you circled 1 and 2, a downward force of gravity and a force exerted by the rope from A to O, and the square answer was those two in addition to force in the direction of motion, so… what do you think about that? Do you still like those answers?
S: Yeah.
I: OK. So, why did you pick one and two for the one you believe?
S: Um, I mean, the downward force of gravity, gravity's gonna be pulling down.
I: OK.
S: The force exerted by the rope pointing from A to O… um… I mean, there's the tension in the rope, I mean, cause he's being pulled down, so that's a force. I said D because force in the direction of the boy's motion since he is… moving. Um, I'm guessing there's gonna be a force there somewhere. I don't really know. I can't really figure it out, though.
I: I guess the thing I'm interested in, the difference between B and D, is that B doesn't have the force in the direction of motion and D has it, right? So… you started to touch on this. Why did your belief answer not include that and the one you thought an expert would give include that?
S: Because I can't really see it in visualizing a boy swinging, I can't really see or visualize the force in this… the motion force, but I'm thinking it's there somehow, because when you do a swing, you kind of swing in an arc, I mean… the motion kind of changes so like, I'm guessing it would have to be there somewhere, I just can't see it, so I wouldn't really put it in my answer, but…
I: OK, so… so 3 is… 3 is sort of a force you think is there but you can't justify as well as the other two?
S: Yeah.
I: OK, OK. That kind of thing is a good thing to know, that's a valid way of distinguishing the two answers that I haven't heard yet, so that's kind of neat.
[rumbling]
I: What else? (pause) Let's look at one of these. This is 28… I think the person A here is heavier, 95 kilograms, B is 77. They're facing each other in office chairs, and they push off. A pushes off on B and they both move. So, you're asked to compare the forces.
S: OK.
I: So, what do you think of those answers there?
S: They're wrong.
I: Both of them?
S: I think so, yeah.
I: OK, that's all right, the point of this wasn't to judge the answers you gave…
S: Yeah
I: and the purpose of… one of the purposes of doing this, I mean, I'm not gonna get to interview a lot of people, unfortunately, but one of the purposes of doing this is we're going to do this again, and see, you know… what did our class do for ya?

S: OK.
I: at least in these kind of areas. So, you marked, you marked D for the belief… for the big guy exerts the bigger force, and the scientist answer was the smaller guy exerts the bigger force. What… how would you mark it now, I guess, is the question.
S: Um, the forces are the same.
I: For both?
S: Yeah.
I: For both circle and square? OK. Do you remember what was going on when you were first doing this and marking it D and C the way you did?
S: Um…
I: I know it's a long time ago.
S: Yeah…
I: I'm sorry about that, but…
S: Well, I guess I was saying A exerts a larger force because he's pushing against him and… uh, I guess I kind of saw B moving farther away.
I: Uh-huh.
S: And C…
I: So, let me just clarify, A pushing off on B, B moves a lot more, that's like the car reacting a lot more in the collision with the truck. Remember that from the tutorial a couple of weeks ago?
S: Mmm-hmm.
I: All right, so where did C come from?
S: Um, (mumbles) B exerts the larger force… Um… I have no idea. Maybe it was just towards the end and I was getting ready to be done.
I: Maybe that's right, I don't know.
S: Cause I…
I: The other survey we gave took a lot longer, but… I'm trying to remember, was this the only thing we gave you that week? You came in discussion for this, so you were allowed to leave right at the end?
S: Yeah, but I had a discussion on Monday, so I wasn't… we had to go in on our own time.
I: Oh, right, so you had to go in on your own time for this, so it wasn't like you were immediately able to go home afterwards, I see.
S: No, no.
I: Well, I like to go home, I don't really blame you. OK. So, you don't know where C came from?
S: Yeah, I guess, I mean, since he's moving away, I guess I was associating that with having the larger force… since he was put in larger motion, I don't know. That could be, I guess.
I: That's fine. If this kind of thing comes up where you're writing down something and you're getting tired toward the end, and you're just putting down answers, I need to hear it.
S: Yeah.
I: Because if it happens, I need to know about it, so I appreciate the honesty.
S: (laughs)
I: Actually, the question right after it… an office chair at rest on the floor, consider the following forces. This one looks kind of like what you did on the rope one. There's a force of gravity, a force exerted by the floor, and a downward force exerted by the air. Do your answers there look like…
S: Well, I mean, 1 and 2 I'd still go with, I don't think 3 has anything to do with it.
I: Was there anything attractive about force number 3?
S: Um, a net downward force exerted by the air. I guess it's just because it added another factor.
I: And that's the kind of thing that physicists do, right?
S: Air is there, so maybe it does actually have some kind of force on the chair.
I: OK, ok. That's kind of neat, I didn't know that's what you thought of us (laughter). You did this sort of thing on a bunch of the other questions…
S: Yeah
I: Um, but they're all… they're all on things that you've actually received some instruction on, so I dunno… I chose not to ask those because you're more likely to have changed your mind. I mean, I asked you the question about the pushing off on each other because I know you've seen it before and I wanted to see what happens when, you know, you've probably changed your mind once, but I don't

need to see you do it a bunch of times. There are a lot of situations like that, where later on you might answer differently.

I think that's all I wanted to do. I just wanted to go over some of these and check the process. Some people, and I want to talk to them too, I've already talked to one or two people like this, they mark down a circle and a square on the same choice for just about every question, and they think that the fact that I'm even asking them to mark two things differently is kind of stupid, cause why should they be different?
S: Yeah.
I: I'm glad I got your perspective on that. I think that's about it.

Laurie's interview

Interview: "Laurie" for FCI survey
Interviewer: Tim McCaskey
Done on 10.8.03

General stuff

I: This is for two things. This specific survey we gave you is one of the things we're doing research on, so it's partially for me, but it's partially for our teaching efforts also. We give this thing out, or at least, this is the first time we're doing it, we're going to be giving it out at the beginning and the end of class, and the point is to see just what kind of knowledge conceptually people got out of the class, and was the class worth anything… before we can go off talking about results and things like that, we have to know if this is telling us useful stuff. I mean, is it worthwhile giving out a task like this? This survey is pretty standard, but the specific directions we gave are not, and so, that's what I'm going to ask about later. So, I guess… before I get into specifics, because it was a while ago that you took this thing, there's general stuff I need to know. What year are you in school?
S: Senior.
I: OK, and what are you majoring in?
S: Wildlife management.
I: OK. So, what are you taking the course for?
S: Because I have to.
I: It's required for the major?
S: Yeah.
I: OK. What did you want to do with that major?
S: I *did* want to open a wildlife sanctuary, but now I've changed my mind, I want to open a dog kennel in Colorado.
I: Oh, OK. The reason I ask is because we don't specifically have a pre-med or pre-vet, and you have to major in something else, right? Did you want to do pre-vet?
S: I did a long time ago, but…
I: Changed your mind?
S: Right.
I: OK, so you're just interested in working with animals, but this course is required for your major?
S: Yeah.
I: OK.
S: Well, the other one is… the one-semester one.
I: The one semester one?
S: 120?
I: Well, this is 121…
S: Yeah, I only need to take this first semester.
I: You're not taking the second semester?
S: No.
I: OK. Would you have taken the course if you didn't have to?

S: No way.
I: How's it going?
S: Horrible. I'm failing.
I: Really?
S: I need a tutor, so…
I: Oh, OK. This (the failing in the course) isn't related to this (the interview), but I'll just talk to you about this because it might help you. Tutors for this do exist, have you tried the course center?
S: No… oh, downstairs?
I: Yeah.
S: Yeah, I go there all the time.
I: Does it help?
S: No.
I: What's wrong? What's the problem? This is useful in the sense that both of us need to know…
S: I dunno, it's just like… you guys just ask the same question I just asked. Like, I know you want me to think about it, but it's not really helping.
I: Hmm. (pause) OK, well, part of it, and you should watch out for this too… is, you know, our job is to make you think about it, right? I mean, you're not gonna understand the stuff in the course unless you think about it. But… it should require more on our part than just reflecting the question back. If you're uncomfortable with that, you gotta say so, and then, I mean, we'll come back with another question, but maybe it'll be a different one that you can think about or you do know how to answer. I can't speak for what the other TAs do, but that's normally what we try to do in the course center. I'm sorry that's not working out. Is lab working any better for you?
S: A little bit.
I: OK. Did you have physics in high school before?
S: Um, I went to school in England, and you take chemistry, physics, and biology all together for two years.
I: Oh, so you had…
S: So I had a little bit of physics.
I: You lived in England for a while?
S: Yeah…
I: And you took…
S: Through high school
I: OK, oh, all the way through high school, and then you just… so, physics was part of a bigger unit with the other sciences that was all lumped together?
S: Uh-huh.
I: Did you get a lot…
S: I don't remember anything from physics.
I: You didn't get a lot out of that class?
S: No.
I: Why not?
S: I don't remember anything, I mean…
I: Oh, OK, so what would you have liked to have gotten out of that, that class?
S: Maybe learning what we're learning now, so it's not so hard.
I: Oh, so what was different about the way you did things there than here? That's interesting, I've never talked to anyone that's taken…
S: I can't really remember what we… I remember we did a lot of dropping things from the air, that's all I remember.
I: OK
S: Cause we had chemistry, biology, and physics…
I: Uh huh.
S: I can't really remember.
I: So it's kind of jumbled together?
S: Yeah.
I: You don't remember any specific physics out of that?
S: None at all.

I: OK. Question sort of unrelated to… well, it could be related to physics class, but it doesn't have to be. How do you tell if someone is an expert at something? So, if someone claims to be an expert in whatever field, how can you tell? What's the… do you have a criterion you use for that?
S: If they know what they're talking about?
I: So what do you mean by "know what they're talking about"?
S: Um… if they're confident in what they're saying.
I: OK. So, it's… to be an expert, they have to appear confident?
S: And say the right stuff.
I: Say… OK. Say the right stuff. Have you ever seen an instance of experts disagreeing on something?
(pause)
S: Um, police officers?
I: OK, in what way might they disagree on something? What do you consider police officers an expert at?
S: Well, I used to work security, so I was in court with police.
I: Uh huh
S: And the police always had to take the stand.
I: Uh huh
S: And the attorney and the police were always disagreeing.
I: Oh, so…
S: and they're both experts really.
I: Oh they're…
S: at law
I: They're experts in the field of law, somehow?
S: Right.
I: OK, so how do you settle it? We'll say you had to be on a jury, let's say, and you have two people that you see as experts, what do you do when they disagree, then?
S: Look at all the evidence.
I: OK.
S: I would go with the cop, though, cause that's what we hired him for. The attorney is trying to win the case for the criminal.
I: So, the attorney in the case, you're talking about the defense attorney questioning the police officer, and you question the defense attorney's motives in that case. Does that sort of taint their expertise? That's the impression I'm getting from what you're saying.
S: Yeah.
I: OK. OK. Now, you can talk about this in terms of physics or whatever else you want, but you've discussed the idea before of understanding something, right? How do you know if you've understood something?
S: If you can go back and do a problem right, or if you get good grades on an exam.
I: OK, so getting good grades on the exam, getting problems right… do you feel you're not doing this in the class right now?
S: No.
I: OK. So logically, is that sort of implying that you don't feel you're understanding the course material very well?
S: No.
I: What do you think you might need to do or we might need to do to fix that situation?
S: I need to get a tutor.
I: OK, what do you hope the tutor would do for you if you got a tutor? What would you like a tutor to do for you to help you understand things better?
S: Well, they would work slowly.
I: Mmm-hmm
S: cause Dr. [PER prof] goes really fast.
I: OK
S: And lab goes really fast, where a tutor can sit there with you and go over one problem for an hour if you want. Cause I had a chemistry tutor, and they were great.
I: Oh, OK.

S: So they just worked slowly with you until you understand it.
I: OK. I understand where you're coming from. That's possible in the course center too, I mean, in the course center, you have a little bit more time to spend an hour on a problem or two problems that Dr. [PER prof] just doesn't have time to do in class. Have you been able to do this in course center yet?
S: No, because there's always more than one person.
I: Oh.
S: I like one-on-one interaction, I can't… I dunno.
I: I mean, the times you've been in the course center, have you always been working with a group of people, or have you been at a table by yourself?
S: A table by myself or with one other person.
I: Or with one other person… but you don't get the one-on-one interaction that you think a tutor would provide?
S: Right. I mean, you might get the one on one, but it's too fast, cause they have to help other people too.
I: Just because there are a lot of people in the room, the person doesn't have… I think I see where you're coming from. That's cool, that's useful information. Part of the TAs job, if you want to avail them of this, if you want to use them for this… you can set up times outside the course center to meet with your TA, or in an extreme case where your TA isn't available, which she should be, with another one… just make an appointment with them and you can talk to them individually. You have the power to do that. You're probably aware of that, but we're willing to do it. I've done this a bunch of times for students that just felt the same as you, that the course center just isn't doin' it for you, you don't think you have the one on one interaction that might be useful. Um, anyway, OK. That's the general stuff. That's setup to talking about this…

Specific FCI stuff

I: You remember getting those instructions when you did this survey? All right, so you were supposed to mark each question on this twice. Like I said, I'm not here to judge whether your answers are right or wrong, you'll go through the course and do this same kind of thing again. Um, also, you should know, when you do this at the end, it's not factored into the grade, this isn't done like a test. If it was done like a test, then people would have reasons to study for it kind of differently, you'd remember… change your studying according to what you know is on the test, and we don't really want that. It's a question of how well you understand things. You were supposed to mark it twice. So, you circle the answer you really believe, and you put a square around the answer you think a scientist would give. (inaudible on tape: snickering) Now, you snicker… did it make sense that we were asking you to do that.
S: Um, sort of, but a lot of my answers were the same…
I: A lot of your…
S: cause if I believed that was the right answer, why would I think a scientist would say (other?)
I: OK. Right, so…
S: But in some cases they were different
I: Right.
S: cause I wasn't sure.
I: Because you weren't sure.
S: of the right answer.
I: Some people take this and put a circle and a square around the same one for every one. Um, for the reason you gave, basically. People are always different, they're always gonna say different stuff. But, a lot of 'em that do that say the same thing you did, that if I think it's the right answer, the scientist… I would think the scientist would say the same thing. Um, on this one, and actually, I'm gonna avoid some of the ones where you did this, because you've already had some instruction on it, but you marked different ones on several of 'em… more than average, just going through and looking at it. I mean, what was your impression again? We're gonna go through some of these individually, but when you had a difference between them, what do you think your impression of those questions was?
S: Well, I'll put a circle around the one that made sense to me…
I: Uh huh

S: and the square around the one that was more technically termed, and I wasn't sure what it meant.
I: Uh huh
S: That just seemed like a scientist would say.
I: Oh, OK. I mean, let me just show you some of them and… that's a general sense, but let's look at some specific ones and you can see if the impression you just gave me holds. 'Cause for a couple of them, I looked at this before talking to you about it, and a couple of them I can see that, and some of them I can't, and I'll ask you about both of those. So, you haven't been shown this demonstration in class yet, right? There's a demonstration where there's a circular track, and a point R that you're supposed to… so, the ball's rolling along and you're supposed to predict which way it's going to go. Now, you have here, as your prediction and scientist answer that it would continue going around in a circle, right?
S: Uh huh.
I: Do you still think that's right?
S: Mmm-hmm.
I: Why do you think that's right? That it'll go in a circle like this?
S: Because (long pause) it just seems like the most logical thing. Cause the ball's already traveling on an arc…
I: OK
S: So when it shoots out of that, it's not going straight
I: OK
S: It just turns, so the ball… (pause) I dunno, it looks like that would be what happens.
I: OK, now, you're gonna do this in a week or so when you work on circular motion, and I hope, I don't know how he's been running the class lately, but I hope what happens is you're going to be presented with a couple of options like this, and I know a lot of the people in the class are gonna say exactly the same thing you did, and some people will pick B and some people will pick C, and you'll have a talk about it and work it out. But, there was a question about… consider the following distinct forces, there's gravity, the force exerted by the channel pointing from Q to O, that's from where the ball is to the middle, a force pointing from O to Q, that's option 4, and a force in the direction of motion, so can you check what you put for circle and square there?
(long pause)
(mumbling)
S: So, it's at q?
I: Yeah, and you're just wondering at that moment what forces are on it.
S: OK.
(pause)
S: gravity is pulling down.
I: OK.
S: And I put a force in the direction of motion. Whatever dir… yeah… what I thought was whatever direction it was going it was just gonna keep going in that direction, because…
I: So there will be a force on it?
S: Right.
I: Right. So, choice E has both of those and… right. (note: choice E also has O->q force)
S: I don't think I really understood the question.
I: OK.
S: So I guessed. I thought maybe… some kind of force (snicker), because this has a wall
I: Uh huh
S: So if you can't go to the O, the ball can't move.
I: Right.
S: I dunno.
I: So, what you said before was that the one you circled, choice C, would be the ones you could make sense of.
S: Right.
I: All right, there's gravity, and this force in the direction of motion. Um… so, do you not understand the question, or do you not understand what 4 is?
S: 4 is, 4. Why would there be a force from O?
I: But you think…

S: I don't think now.
I: All right.
S: At the time…
I: But do you think a scientist might say that there is?
S: Yeah.
I: OK. Because…
S: He'll say something like… it's on a down slope and…
I: Actually, the ramp, the circle is supposed to be like this (makes circle horizontally on table), right? This is supposed to be the top view of a ring like this. And the ball…
S: Oh, so, like… the center of gravity.
I: Uh huh? So, a scientist will talk about the center of the circle and they'll say that there's a force going to it?
S: Yeah.
I: OK.
S: There's a wall, so it can't go to O, but O has an effect on q.
I: But you don't understand why we would say something like that? OK. So, this is an example of a question that's pretty consistent with what you told me… that you mark down one what you think, and something confusing to you that a scientist might say, you'd mark for the other one. That's fine. Another case where it's not so obvious that we can do that is this one.

Ball/string thing. (neat example)

I: 7. You have… a steel ball attached to a string, it's swung in a circular path in a horizontal plane, so again, this is a top view of someone swinging a ball over their head like this, right? At P, the string breaks. So, what path does the ball follow after the string breaks.
S: I said A because it's already going in a circular motion.
I: Does A… A looks like…
S: just like
I: sort of like choice A in #5, right? It'll sort of continue that path?
S: Right.
I: OK, so, do you still think a scientist or expert or whatever will say choice B, that it goes in that direction after the string breaks?
S: Yeah
I: OK
S: Because… (pause), because they would say there's nothing making it go the same direction. It just seems logical to me, because the velocity is going in a circle, it would go to A. But I think a scientist would say B, because there's nothing making it go in a circle, except for when you're swinging it, but when the string broke, it would just fly off… so B.
I: OK, all right. That sounds like an explanation that a scientist might potentially give. Now, is it worrisome to you at all there's a difference between these two answers? That you believe one, and you think…
S: Yeah, I just wanna know which one's right.
I: OK. How might you… how might you sort out then which one is right?
S: Conduct the experiment.
I: OK. That's one way of doing it. The experiment is a little bit hard to conduct, because it's hard… it's hard to swing a rope above your head and break it at one specific point, cause the break has to be completely instantaneous, it depends on what you're using to break it. I would never do this in a class, but let's say hypothetically myself as a TA or a professor were to just tell you B is right. Would that fix everything for you or not?
S: Mmm-hmm. Yeah.
I: Why?
S: Because I can understand why B could be right.
I: OK, would you be willing to throw out…
S: A?
I: Yeah. Are you comfortable doing that?
S: No…

I: OK.
S: Cause it just seems logical, but I've learned in this class… I dunno.
I: No, go on.
S: I've just learned in this class that everything I think is right is wrong. So I believe B.
I: Everything?
S: Basically.
I: OK. I guess that's a bit alarming to me. Yeah, in physics, it's inevitable. You're gonna come across situations where you think one thing is gonna happen and what happens in the experiment isn't exactly right. The case of… you saw the demonstration, right, where you ram the two cars into each other and the forces on them were the same?
S: Mmm-hmm.
I: Did you think they'd be the same? If you have a car, a truck ramming into the car, did you think the forces
S: No.
I: would be the same?
S: No, the truck will have more, cause it's bigger.
I: Right, and everyone says that, right?
S: (mumbles)
I: That's an example of a case where you see something that's wrong. But the point of going through the tutorial when we said the car is twice as massive… 1000… er, the truck is 2000 kg and the car is 1000, we said the truck slowed down by 5 m/s. What did you say the car would gain in speed?
S: Nothing. I don't know, I don't remember.
I: All right. The car was parked, right? And the truck hits it, and the truck loses 5 m/s of speed, how much speed does the car gain?
S: Whatever it hits it by.
I: Um…
S: So the truck hits it, and it goes backwards… does the car go backwards?
I: No, the car moves in the direction in the truck was moving. The truck doesn't go backwards, the truck keeps… because it's big, it keeps going forward but it loses some of its forward speed.
S: I don't know.
I: The only reason I bring it up is that our experience is that groups are willing to say or at least sympathize with "the truck will gain 10 m/s" (meant to say car), if the truck is moving slow, the car will gain 10, because the truck loses 5 and the car weighs half as much.
S: Oh.
I: Does that seem reasonable?
S: No.
I: It's not the only instance, but we put some of those in the tutorial where, you know, you have an intuition about this, and later on in the tutorial, it turns out to be right.
S: Right (non-sarcastic, I think)
I: So, we don't want… we don't want physics to be about "we'll show you where you're wrong and then fix it." Sometimes, you're gonna be wrong, but sometimes you're right, and if you carry it through, you're gonna get the right answer. Um, now… in talking with… let's say you're talking to a professor or a TA about this. Do you think you could get them to agree… say you think that we're gonna say B. Do you think you could get us to see your point of view, that it should follow a path like A?
S: Yeah.
I: OK. How would you try to do that?
S: Because it's not going to do the same thing every time. It could be either.
I: So you think when you do this, some times it will do one and some times it will do the other?
S: Yeah. It depends on how fast the ball was actually moving.
I: So which is which? Let's say the ball is moving quickly.
S: I think A. If the ball is moving slowly, I think B.

End neat example

I: Oh… so all right, that's useful information. Um, let me see if I can find another example… (pause while a search is done) I should have just marked 'em down. All right. Let's look at this one. So, we're almost done. This is the last thing I ask you about. Along a frictionless path… so in this question, you have a puck moving along a path from A to B, and you give it a kick
S: Mmm-hmm.
I: You give it a kick at B, and you're supposed to choose a path for which it moves, and you've done that. So, after receiving the kick, this is like the example on the last one, what forces are acting on it? So… check out what you wrote.
(pause)
S: Right.
I: OK. So, do you still think that that's it?
S: Yes.
I: OK. Just a downward force of gravity? What's inside this scientist answer you picked? C?
S: Um, it just seemed like more words. Like, a scientist likes to use a lot of words, and I just figured that… they'll say that the surface that's holding the ball up… like a desk would hold a book, and a horizontal force… I don't think I understood that, I just put it because it was wordy.
I: OK, so, characterizing scientists as wordy. You're not the first person to do that, and I've done it before too, even though I work with scientists and sometimes call myself one. That kind of thing happened a lot here, and I just wanted to make sure that was going on. But I think… this problem here I was showing you with the whirling the ball around your head doesn't involve any words, so that's the reason I asked about it.
S: So what's the right answer?
I: All right, well…

End tape

Editor's note: after the tape ended (I should not have turned it off), she and I discussed this example for about ten minutes. I didn't give it away, and worked it just like we would in the course center. I asked what velocity was, and made sure we got to a point where direction was brought up. After that, I had her answer questions like:

Ok, if the ball's direction is changing, is it accelerating? (yes)
What then do you need for an acceleration (we then talked about the forces a bit)
Ok, now, once the string breaks, are there any net forces on it other than gravity?
What's the implication of that?

And she then got the right answer. Now, having seen her later, I'm not convinced this stuck. She completely forgot the truck/car tutorial example when she asked me to "explain momentum" to her in course center recently, and I'm pretty sure her low level of scores and confidence in the class has remained. Her TA had reported to me she has no interest in reconciling even though there was a faint glimmer of that here.

Leila's interview

Interview: "Leila" for FCI survey
Interviewer: Tim McCaskey
Done on 10.17.03

Prelude

I: This doesn't affect your grade at all, and it says that… I mean, I already explained what the purpose of the interview was, to get some background on you and then get some information on the survey we gave out. And it also says that if this reported, um, if results from this, if I want to quote anything that

you or I say, it'll be done so anonymously. I mean, I'd be the one presenting it, so I wouldn't be anonymous, but your name would be.
S: OK.
I: So, this is the specific one, do you remember this?
S: Mmm-hmm.
I: OK. We'll get to that in a bit. Just some background things first.

Background

I: I guess the first one… that I've gotten a lot of interesting responses to so far is how's the class going? I mean, you sort of talked to me about that.
S: Uh, I think the class is pretty interesting, actually, I mean, I think it makes less demands on my time as opposed to the other physics class that would have been offered at this point. I remember orgo last year, you know, had chapter problems every couple weeks, and we were always stressing about that, so the class in terms of *stress-wise* [mmmhmm] isn't as stressful.
I: OK.
S: And, um, so, I didn't do well on the exam because I misread the first question, but I did take up the makeup. I did take the makeup yesterday.
I: Did the makeup go better, do you think?
S: Uh, I dunno. I've learned not to trust my instinct.
I: With respect to how well you did on a test?
S: [laughs] Yeah, exactly. So, I dunno. But I think I was more mentally present, like, I actually try read (sic) the question really well [mmm-hmm], that my answer corresponded to the question [yeah], yeah, so, there was more of that, so we'll see how it goes.
I: That's a big thing on these tests, you have to know exactly what we're asking, and if you take enough time to figure out that, then sometimes the answer comes more easily. You said the class seems less stressful to you? [mmm-hmm] than another option? What do you mean?
S: Uh, I think there was a class offered 10 to 11, 10 to 11 (other prof)'s class. I had a friend in there and she's like, dying.
I: Oh, this is another professor for the same course?
S: Right.
I: OK. I've not met this person. I've taught 121 before in a more traditional sense, but never with him. That just seems like it would be more stressful to you?
S: Yeah.
I: Why? More time?
S: Yeah, like, she has to… she just needs to know all these different equations, and, like, her exam was basically, I think she said multiple choice, but you have to work it out. So it's just a lot more stressful, I think it would be a lot more like the previous orgo, or whatever, where you have to do all these chapter problems, practice, practice, practice, and you know all the stuff.
I: OK. You took orgo? What's you're major?
S: Physiology/neurobiology.
I: Are you a premed?
S: Mmm-hmm.
I: OK, so you have to take this course cause it's required.
S: Yes.
I: OK.

Gripe about the class?

S: What worries me is that, after I got my exam the other day [uh huh], I was like "man, so this class…" I mean, a lot of people say the A is very achievable, you know, very… [mmm-hmm] and I was like if I don't get the A, and I was like, well, I'm not really learning for the MCAT, right, cause I'm taking a prep course, so I'll be learning some physics there, but right now I don't think that the class is really tailored towards premed students, do you know what I'm saying?
I: This class?

S: Yeah, like… cause the way I understand it, which is probably a very flawed understanding, cause I don't really know much about the MCAT just yet…
I: Mmm-hmm
S: But I think that there's definitely gonna be more of a… applying equations, maybe to a greater extent than in this class. I was like ok, so if I don't get the grade and I don't get the MCAT knowledge, I was like, uh, this is gonna be a fiasco! But…
I: That would be unfortunate.
S: But, I think, I'll finish it. I'll do well.
I: I mean, just to sort of address that concern, the class is about 30 or 40 percent premeds, I would guess. It's about 70% life science/biology, and about half of those people are premeds. We've had a bunch of them go through this class before, and I've talked to them as they were preparing for the MCAT. And… their one complaint isn't that they're not learning MCAT stuff, but rather just because we have to take more time in lecture and in tutorial to get through some of the concepts, there is some stuff that's covered in a first semester class [uh huh] that we might not get to in as great a detail as the MCAT gets into. But it's a bit of a tradeoff. There are people that cover the whole body of MCAT material and because they haven't taken time to go through it, so they don't understand the individual pieces as well, so…
S: Right.
I: You're kind of getting a trade, and presumably, studying for the MCAT you'd pick up on your own through your course or whatever else anything you missed, so that's fine.
S: But overall, I'm pleased with the class.
I: OK. This isn't gonna get back to (prof) now, I mean, he hears plenty of compliments and complaints on a daily basis, so…
S: But I think it's a nice way to have… it's nice to have the students be the focus really, you know, as opposed to whatever else is going on, so…
I: As opposed to what?
S: As opposed to the professor just like, not even, you know, there's a big wall there.
I: Between you and the professor, you mean?
S: Yeah.
I: The transparent…
S: They just sit there, and write the stuff on the board, and, you know, they do their thing for an hour, and leave.
I: And they talk to the board [exactly], and there's a transparent… sort of a transparent wall between…
S: Right, so it's nice to know that the professors and the TAs are all… like, the research is being done, the students say we kind of feel like, oh, OK. [laughs]
I: This, actually, we've been doing this for three years before, and even when we were doing it the first time, it wasn't entirely new [mmm-hmm], but there's always stuff we're doing to it. Did you have physics in high school?
S: No. I graduated high school early, so I graduated in three years…
I: One of those smart folk, uh?
S: In my third year, when I should have taken physics, I… you know, cause I think it goes… I think I went biology, chemistry, and it would have been physics my third year, and I just took anatomy/physiology class.
I: In high school?
S: Yeah. It was really cool, because we got to dissect a cat and a rat, and it was like, really awesome, so… I think… at that time I was like, "yes", I definitely ducked physics, you know, I was like "phew?", but it came back to bite me.
I: Not really. I mean, some people feel that not having physics before hurts [mmm-hmm], but I feel noticing some people that have had physics, they've had it in the sense where they had to memorize a bunch of stuff [mmm-hmm] and they're not ready to do it the way we do it, so, it's fine. This is, material-wise, equivalent to what you would get in a first semester high school class, just kind of presented in a different way. Maybe a little quicker, with some more thinking and labs and stuff involved, but…
S: Right.

Expertise

I: OK, so you didn't have physics. So, now, sort of away from the physics class track of questions, how do you tell or judge if someone is an expert at something? Doesn't have to be physics.
S: (pause) Um, how do you judge if somebody's an expert [mmm-hmm] at something? Usually they let you know that through their, like, they'll seem very knowledgeable, so if you ask them a question, they'll give you a nice, detailed, *friendly* answer, like something you'll actually… It won't be…
I: Friendly in what way?
S: There's two ways, because somebody can give you this answer to a question, or can fill you on some things that they're an expert in.
I: Uh huh
S: through these big words, specific jargon that they use, and then you think, oh wow, they must know what they're talking about *or* a really good person will tell you the same stuff but in layman's language, and you'll be able to maybe connect with them in that sense, and I think that probably shows somebody who's more of an expert in what they do.
I: So you prefer the latter of those descriptions a little better, rather than someone…
S: Yeah, although the first one will seem really magnificent, but in a very strange way, like, you know, distant, like, oh wow, he must know what he's talking about, but, you know, I don't.
I: I'll never want to talk about that over dinner with him or her, or whatever.
S: That's right.
I: OK. What do you do in cases if you've got two experts on television or if you're talking to them in person and they disagree on something? Right, if you have these two people, suppose they're very well practiced, we'll even use the definition that you like, that they're both used to talking to people in sort of layman's terms, but they're disagreeing on something, how do you sort that out?
S: Am I trying to form my own opinion?
I: Um, I suppose, let's say you're trying to evaluate for yourself which of… yeah, basically you're right, which one of the opinions to
S: adopt
I: adopt, if they disagree.
S: Well, if they're disagreeing, I would, you know, mentally outline their points or something and try and see which one I agree more with, so it would just be personal.
I: OK.
S: Which one is more tailored to… well, see, it depends on what the field is, but if it's something like physics, I have no clue, but if it's something like where values and stuff are…
I: ethical or political, maybe?
S: Yeah, so I guess I'd be inclined to kind of, according to my values, my background, my… everything.
I: It would be a match against yours… but physics just seems different to you?
S: Yeah, I wouldn't, I mean…
I: Do you think experts disagree in physics?
S: I'm sure they do, but like, last year, a friend of mine who's really into physics invited me to come to this lecture by Dr. (different prof)…
I: In this department? Sure, I know him, he's good.
S: And it was supposed to be a lecture for laypeople about *string theory*?
I: Yup. That sounds like something he talks about. I've seen that lecture too.
S: So, I was there, and I felt really out of place, but… I went, my friend wasn't there, he just said to go, and so I just came, and all these people really looked like physics people, and I was like "wow".
I: Was there any expert disagreeing going on?
S: No, but I can see other people disagreeing.
I: With him?
S: With his little string theory. I can see other people, somebody who's just as high up on the, you know, the ladder saying, "oh, well, Dr. (whoever), I disagree with that, I think they're actually not strings. They're… cubes," or, you know. So I could see them disagreeing in that.
I: OK. You don't think you'd be able to work out that disagreement for yourself?

S: Cause it's too, it's too advanced, but I guess in basic physics, then, nobody would disagree, right? I don't think there's disagreement in basic physics, like, you know, things fall to the ground, stuff like that.
I: About that stuff, among people with PhDs in physics, not much. I mean, they'll disagree until the cows come home over how to teach it or how best to think about it in some senses, but they're not gonna… weight is mg on the surface of the Earth no matter who you talk to, I think. OK, that's pretty cool.

Understanding

I: Concept-wise, in the course, do you think you're getting… you're understanding some of the concepts that are coming up in tutorial, lecture, or whatever.
S: Yeah, I think I'm understanding them well. I wish that, one thing I wish was different, um, or helpful, I think, you know how I said I didn't like the whole stress of orgo and other classes where you had, like, weekly huge list of problems to do, and stuff like that?
I: Yeah.
S: But here, you have the five problems [uhhuh], and it's fine, cause I think the five problems are the objective of the course [mmm-hmm], they're tailored so that they prepare you for the exam. But I think it would be nice in terms of making us understand the concepts better to maybe have some student-friendly problems to kind of help us to drill that idea of all the physics behind it, like, all those equation stuff.
I: Student-friendly in what way?
S: Student friendly in that it's not as laboring as you would get it in (other prof)'s class, the other professor, where my friend's suffering in his class. [uh huh] So it's not as laboring, but it's still, you know, more… just a tad bit more *equation* stuff than this class. So it would be kind of meeting somewhere in the middle, where there's just as much theory, and it's all beautiful, but perhaps maybe even a little suggested problem list, or something, for… if this concept is not clear, why don't you consult so-and-so book, and try problems…
I: Do you have Cutnell and Johnson? It's the text he recommended for this class.
S: Yeah, I have that, and it helps me to read it sometimes, when I want to, because, I mean, I don't think the (mumble) with the readings, but, it's like, you know, what I'm reading is kind of related to what I'm taking in class, but there's a lot more stuff going on in the reading [mmmhmm], and I'm not sure how much of it to take in. I'd like to practice some problems, but I'm not sure which ones.
I: OK, well, he would say you're always welcome to do that, but, I mean, that's right. He doesn't give suggestions for sort of the plug-and-chug formula problems in the back because, and I'm trying to put words into his mouth, but he probably doesn't think they're useful, but you're free to do them if you think it would build confidence for you. How do you know if you've understood something in this class?
S: Um… (pause) hm… let's see. (muffled) How do I know if I've understood something in this class? I really don't. It just kind of happens. Like, I know that's not the answer you want.
I: [laughs] heh. What's *that*? You're being brutally honest, and that's more than I can ask for, so…
S: It's just, it kind of happens. Like, you go to class, and you do the ILD, and you do everything else, and the tutorial, and the lab, and stuff just kinda diffuses into your head while you're just sitting there, but I think, like, for example, going through… tutorial and… I think the tutorial is probably very helpful, because it helps give you some straightforward applications…

Newton 3 understanding

I: Which one of those tutorials do you think has been the best for you so far?
S: Well, the one we did yesterday, the momentum one, was OK, it was good, but not as strong as the force equals ma one, the whole… the truck hitting the car, and then we saw the two…
I: Oh, the Newton 3 tutorial.
S: Right, that one was really helpful. The momentum one, I think, wasn't a runner up, it's the most recent in my mind.
I: Right. OK. So, it's recent, and it kind of helped.
S: Mmm-hmm.

I: I'm kind of eager to talk briefly about the Newton 3 one because some of the questions on this (taps sheet) directly touch on that. You said that was helpful. Did you feel you understood what Newton's third law meant at the end?
S: Mmm-hmm.
I: OK, I mean, how do you know? How are you convinced that you *got* it after the tutorial was over?
S: Do you want me to tell you, like, I *refined* my intuition, you know, using you all's language. OK, do you want the (Leila) answer?
I: Um, well, yes. You don't have to tell the story about how the tutorial did that, I mean, cause I've taught it and I've seen it. A lot of people I've interviewed mention this same thing [mmmhmm] that this Newton 3 thing was pretty compelling, but what was good about it for you? Yes, and I always want the (Leila) answer.
S: I think, OK, so the car and the truck, I would have never believed anybody who said that, you know, they were equal forces. I would have never believed that. But when I saw the little carts with the more weights and with the little computer, and it showed you the force [mmmhmm], and how they both were equal and opposite [mmmhmm], um, that was like OK, this is real, so let me think about this, you know? They're not, like, messing with me [uh huh], and then I realized that it's not really what I… I realize that it's really more of a… it wasn't that I just wouldn't understand it or wasn't going to, but it was more of a "fixing my language" [mmm-hmm], so I knew something wasn't equal. Like, something wasn't equal and opposite, and it was the acceleration.
I: Right, yeah, and you thought that, and that was right.
S: Right, and so, that's how… how did I come to that conclusion? What are you…
I: No, I'm just trying to reiterate what you… make sure I understand what you said.
S: Yeah, when you said forces are equal and opposite I said no, that's just not right. But then, I saw the graph, and I was like, OK, so maybe there's a grain of truth there, and I was like… and then, when we learned about the accelerations being different, and (ask?) "oh, that's what I was looking for." So I learned that I needed to use my words the right way.
I: OK, but you were convinced at the end that there was something about that that you knew and was correct, and there was, I mean, there is something different [mmm-hmm] in the tutorial that helped you work out what that was?
S: OK.
I: OK, that's pretty cool. That was a longer time than I'm used to spending on the general stuff, but, I mean, we had some interesting stuff to say, you had some interesting things to say, so that's cool.

The task

I: Let's briefly go over this. You remember the survey we gave you? These were the instructions. Do you remember the instructions [mmm-hmm], that you were supposed to circle what you believe and square the answer you think a scientist would give, or call it an expert if you want. Normally, when this is given out, the survey is just given out with a bubble sheet and people give one answer for each question. So… this is nothing new, but the instructions are. Did it make sense that we were even asking you to do that?
S: Um, well, I knew that the course was a little bit different, so I expected stuff like that to happen, and I was like, 'ok.'
I: Stuff like what?
S: Like having a question where you give two answers. I actually went along with you guys and I did give two different answers for some things.
I: Is it because you wanted to do it, or what?
S: No, cause I was following the instructions.
I: The instructions also say that you have the option to square and circle, so you were fully within your rights to square and circle every question. I mean, in what way… how did you take that… "following our directions."
S: Because there are some things that I was like, OK, I have no physics, so this is what I think, but somebody with more physics would probably… you know… you know how sometimes you narrow things down to two answers?
I: Yes.

S: So, I picked the one I would pick, and I squared the one that might be the right answer, you know what I'm sayin?
I: OK, OK, so, let's actually look at a couple of these and see. Let's see…

#4

I: OK, I'll pick some that you've already gotten some instruction on, then I have a question on one of the ones later, and it'll be about half an hour that we've spent in about five minutes, and I don't wanna make you late, so…
S: That's fine.
I: This question here. Car and truck. A large truck collides head-on with a small compact car. This is what we did in the tutorial. [mmmhmm] So, you're supposed to pick which of the forces you think is right, so, can you… you circle "the truck exerts a greater amount of the force than the car exerts on the truck" and you square "the forces are the same." So, why did you do that? Why did you decide to circle this one?
S: Because that's what I *thought*, and that's what I thought up until the tutorial.
I: Until the tutorial, that's fine. So, what was attractive about answer E that made you square it at the time, do you remember?
S: Because it seemed like that was something a physicist would say, like, it just seemed so… well, let's see. It was the car exerts a greater amount of force, that wasn't anything. Neither of them… you know, neither of them… this is dumb. Neither of them gets smashed, or the car gets smashed cause it's in the way of the truck? No.
I: Mmm-hmm.
S: The truck exerts… the car doesn't exert a force on the truck, that's not right. Like, there would seem to be. So, this one seemed like the runner up to my initial feeling, and it seemed like, ok, this is something that, you know, a professor or somebody with a whole lot of knowledge would say, it just seemed like one of those quirky things about physics and sciences, you know. It's totally what you don't expect, so…
I: So, you expect the physics answer to be something you don't quite get at first, and it's a little quirky looking, so you put… all right. Is this worrisome to you, like if you were to do a survey like this and you had the impression that there could be these two answers, does it bother you at all that there's a difference?
S: Well, I guess it's a problem when you're taking a multiple choice test, you know, you're sometimes stuck on two different answers, and it's worrisome there which one is right.
I: Mmmhmm
S: And then, you're supposed to be the expert, so you're supposed to know the right answer, not what you think versus what the real expert thinks.
I: Mmm-hmm.
S: So, it's worrisome there, but on a survey, like, in a physics class, like, I dunno. It wasn't really worrisome here because it was in the beginning.
I: And it didn't count for anything.
S: Exactly. It was like a "get to know each other" type thing.

#15 (N3, different context)

I: Let's see. Cause in some other questions, like on this one where a car is pushing a truck. [mmmhmm], and they're speeding up [mmmhmm], you circled and squared the same thing. At least, I think that's a circle.
S: Right.
I: That the forces are the same, on #15.
S: Mmmhmm.
I: Does this question seem different to you?
S: While the car, still pushing the truck, is speeding up to get up to cruising speed, the amount of force with which the car pushes on the truck is equal to that with which the truck pushes back on the car (note: she's reading choice A).

I: Uh huh.
S: So, why did I answer this one different from the beginning?
I: (referring to #4) From this one. Does this seem like a different question to you? Is there anything you can remember about that?
S: Well, it seemed to me like when they were moving (mmmhmm), if they're moving, so the force the car is exerting on the truck to move it is equal to the force the truck's exerting on the car, so it has to move it. I don't know if I really remember what I was thinking, but it just seemed like when it was moving, they're both maybe, you know… this one had to push it, and so the car had to push the truck.
I: OK.
S: And so the truck needed to be pushed, so there was equality there.
I: OK, so it's different in this one, because this is just a collision, and in this, you're moving.
S: Right, yeah.
I: OK. That's kinda neat. Right. The questions cover the same physics, but if this distinction exists, I wanna know about it. The last kind of thing I wanna ask, and this'll finish it up, are on these questions, because they're… I'm interested in them primarily cause you haven't learned the answer in class yet. He's gonna do this (points to circular track) demonstration, I don't know if you remember the question, but there's a circle shaped channel that goes from P to Q to R, and then the track ends at R. You're supposed to pick which direction the ball's going to go. So, you haven't seen this demonstration yet, he hasn't covered it yet, and you didn't do a circle/square answer on this one. [mmmhmm]. OK. Can you react to this now, possibly even in the sense that we asked on the survey? Can you pick an answer you believe and and answer a scientist would think? They can be the same if you want.
S: OK. So I said B here, and this one I had trouble with, cause I really have to visualize and try to feel what's going on, and what would it do, and, imagine some things…
I: Uh huh.
S: Um, so, right now, I think I would go with my answer B, that after rolling in a circle, it would go straight ahead, because, you know, but then, a scientist would probably say A or something.
I: A scientist would say A, and why do you think a scientist would say A?
S: I don't know, flipping through the book, so I don't know if this is something, like, that has to do with centripetal stuff, or motion, or… I dunno, but maybe.
I: OK.
S: So it would be my guess, and that's based on the fact that I had to flip through the book to find an answer for a question, came across centripetal force, and so *maybe* it has something to do with it.
I: But you still believe B?
S: Yes.
I: OK. Do you think, I mean…
S: Now, I have to… if I haven't done an experiment, so I don't know.
I: Yeah.
S: But this is my guess.
I: That's fine, that's fine. But, I mean, let's say you have this intuition, and someone disagrees with you. Do you think you could get them to… (pause)
S: Convince them of my thinking?
I: Yes, could you do that?
S: Like, just using my talking, or doing an experiment, or, like using variables and equations, or…
I: No, you haven't learned the variables and equations yet, but I mean, you were just trying to explain it, right?
S: Mmm-hmm.
I: Could you explain and convince them why it makes sense to you?
S: Um, I'll just say that if it's rolling, like, in the little path for it, and it just gets off of that, it'd seem to me like it would continue straight at that time. Now, going… (pause) I dunno. Like, there would be no… like, there's no tension or, or this ball here's moving in it's little path, but it's moving, right? It's moving in its own way [uhhuh], and this path is limiting it to a certain direction [yeah], but if it were to be freed from this path, I think it would just go straight.
I: OK. And, so that's how you would try to convince someone of your point of view?
S: Right. Because there wouldn't be these little barriers telling it where to move.

I: OK. The… do you think there's any way you could come to understand this, if someone tried to convince you that A was the right path?
S: Is A the right path? (laughs) Um, I could see both ways, like, I could see the fact that, OK, without the barriers, the ball would just go in its own little way, like, straight.
I: Mmmhmm.
S: Because that's just the tendency of things, to kind of maybe go like that. But, um, I could also see that… well, see, I could probably if I had another tutorial or anything (mumbled). But, I think, because the ball also, like, we know how the ball doesn't really feel thing… it feels what it's feeling at that time.
I: Yes.
S: So it wouldn't be feeling this pathway, so if you were to argue, "well, it's been going in this motion, and so therefore it will continue in a circle," my counterargument will be, "well, there's no… it's not feeling that circle anymore, you know."
I: OK. So, you're more convinced that your intuition is right in this case?
S: No. I'm not convinced, but I'm giving you arguments on how I would try to convince you or give you a counterargument when you tell me that it's A.
I: Oh, right, but you want to hold on to…
S: Yes.
I: OK, OK.
S: It's like I don't know enough to say that it's A yet, I know more about my intuition.
I: OK.
S: But if you were to say A, I would fight back with whatever I just said, and then… then eventually you guys would win me over…
I: So, do you want a self esteem boost?
S: (laughs) No, it's just… I think it's… go ahead.
I: Your uh…
S: No, I think it's, I think it's B, but, I think it's also… (pause) I mean, I think it's B, but I think it might be A, but I have some reasons for why I don't think it's A [OK], and that's all I have right now.
I: OK. And I will end by telling you that those are good reasons.
S: (laughs) thanks.
I: Right. I mean, you're gonna have tutorials on centripetal… centripetal… circular motion [mmmhmm], I shouldn't use the word centripetal because that describes forces, and stuff [ok]. Um, OK, you're gonna have stuff on circular motion, but this'll be an experiment you do, and that's the kind of arguments you're gonna make if you talk to your neighbor for a clicker question, let's say.
S: Right.
I: So, I would say, if you believe it at the time, go and do it, and if anyone in class tries to convince you of A, I mean, they're gonna run into this problem that you described, they're not gonna… they might be able to give an explanation, but you might not buy it. [mmmhmm]. Right, and your reasons for picking B are good reasons.
S: Is it B or A? (laughs)
I: Does it bother you that there's this difference, possibly?
S: Yeah, I mean, I just wanna know if it's, you know…
I: So, after it leaves, right, what's the direction of its velocity? Which direction at this point R?
S: Its velocity?
I: Yeah.
S: Well, it's been changing all this time, right, at some point it was like this, and it was like this, and it was like this (*ed note: I'm sure she was gesturing up a storm here.*)
I: Uh huh, what is it at this moment?
S: Straight.
I: Straight up.
S: Uh huh.
I: OK, and, so, you need a force to change that, right?
S: Right.
I: Now, once it's released, are there any forces?
S: No.

I: It's exactly your argument, wasn't it?
S: It's B!?!? (laughs) Ha ha! Good.
I: So.
S: I don't know why I thought A, then. OK, because, remember, I had flipped through the book, and I thought it might be A now that I…
I: What in the book did you find?
S: Something about cars and going on a circular path, and I was like, mmm, maybe that has something to do with that. But I'm glad I sticked with B.
I: All right, all right. You have a meeting now?
S: Yes.
(end of tape)

Sarah's interview

Interview: "Sarah" for FCI survey
Interviewer: Tim McCaskey
Done at 2 PM on 9.24.03

General stuff
I: OK, so, I'm not gonna get to this [the FCI] yet, the general stuff will come first, so this will be sort of quick.
S: OK.
I: So, what are you majoring in?
S: My double major is biology and secondary education.
I: OK, what do you want to do with that?
S: I want to be a high school biology teacher.
I: Teach biology… so you don't have… you're not like a bunch of the other biology majors that are trying to do pre-med or something like that, you just want to teach?
S: Yes.
I: That's pretty cool. I was something like that when I was undergrad, I was gonna be a secondary school physics teacher and then I found that there were groups in grad school that did research on teaching, so I was kind of interested in that… we definitely need more good teachers.
S: Oh, you're telling me!
I: How do you know?
S: Oh my gosh… some of the teachers I've had throughout the years have been horrible!
I: Pretty bad… what year are you?
S: I'm a junior.
I: OK, yeah, most of our class is juniors and seniors, so that's pretty standard.
S: Yeah.
I: OK, what are you taking the course for, is it required for the major?
S: It's a requirement.
I: Did you have any particular desire to take it?
S: If I had the option, I probably wouldn't be taking it, I'd just be sticking to biology courses, but because I am required to take it, I'm taking it, and I actually really like it.
I: OK, this is kind of off topic, but you've already mentioned it… so, you thought you wouldn't like it, and it's been going OK?
S: Yes.
I: How's it going? What do you like about it?
S: I like the fact that every time I think something is gonna happen the way I think it is, it doesn't… not every time, but, you know… a lot of my… like, today in tutorial, a lot of the common sense intuitions you had were proven otherwise.
I: OK, so you saw the experiment, for example, you just did today [force probes on a heavy and light cart showing N3 equal/opposite forces], and that wasn't the result you expected?
S: No.

I: Oh, really? OK. All right. Did you have physics before in high school?
S: I had it once in high school, and I didn't learn much from it because it wasn't a good experience.
I: Just a one-year… standard physics thing? No calculus at all… was it sorta the same math level that we're using?
S: Um, I can't remember, it was junior year of high school.
I: OK.
S: Which is pretty long ago, actually.
I: For me too.
S: [laughs] was it for you? Probably, but… if I remember… lower level math, and stuff.
I: OK, but you didn't think you got a lot out of it?
S: I didn't. I know I didn't get a lot out of it… because I didn't like my teacher.
I: What was the problem you had?
S: Well, my problem was that my teacher was not very good, and she would often do examples of the problems we had, and she would leave out steps, so we were always correcting her on how to do things, like math problems… simple math problems, we were always correcting her. Does that make any sense?
I: I think so… do you mean… the first thing you said to me was something like "leaving out steps," so skipping from one step to something farther ahead without doing something in between? Is that what she did, or would there be mistakes on the board?
S: Mistakes, too, she would leave out a step and then she would never incorporate it at all, so then the calculations would be off, and then the final answer would be off. So, it wasn't just like… her trying to do it on her own train of thought, cause… I don't know. Do you get what I'm saying?
I: Try again, I think so, but say what you said again.
S: She wasn't leaving out steps to take a shortcut, you know… to get to the same answer. She was leaving out steps and making mistakes, so she would end up with the wrong answer.
I: OK, OK, I can see how that would be distracting.
S: Well, there was that, and also, she wasn't a very good teacher, so she didn't keep our interest in the subject. We were pretty much just focused on memorizing stupid little things you had to know to get through the course than actually understanding the concepts that were involved.
I: Oh, right. So, you mention "not good," I was going to ask you to elaborate on what you meant by that, but I get the feeling now. So, you didn't get a lot out of the class.
S: No.
I: OK, something not related to physics, you can answer this in any way you want, but… when you think of someone as an expert in something, how do you know that someone is an expert?
S: When I think of somebody as an expert, I think of somebody who has a lot of knowledge pertaining to the subject that they're an expert in, but who also can teach that knowledge to other people, you know, so that they learn very well, and to also… pretty much that.
I: OK, so, being able to explain what they know is an essential part of it?
S: Yes.
I: OK. So, the next thing… this doesn't happen as often in early physics classes, because physics professors often agree on things, but sometimes experts… two that are in the same field, will disagree about something, and each in a debate would try to convince you that what they do is right. What do you do when experts disagree? Have you come across this situation recently?
S: No, I've never been in that exact situation, but if I were one of the experts disagreeing with, say, you on the subject, I would want to talk it out, you know, and hear what your viewpoint is versus mine, and then try to work it out and see which is the correct one.
I: OK.
S: Does that make sense?
I: It makes perfect sense. You were talking before about understanding concepts, right, that there was a deficiency in the class you had. Suppose someone was trying to get… whatever way they could… you to understand something, how do you know if you understand something?
S: When I can apply that concept in any… any different situation I'm in and use it successfully, you know… come out with the right outcome. That's what I would think.
I: Come out with the right outcome as in… get a couple correct answers on different…
S: I get the right answers or know what's going to happen.

I: Oh, like in the tutorial, if we were to give you another situation with the force carts or to make a velocity graph, you'd make the correct prediction?
S: Yes.
I: OK. [irrelevant comment about my attempt to create a context]
S: but not… I don't want to be able to memorize it, I want to be able to understand it and know what's happening, you know… why it's going against my common sense, not just…
I: OK
S: That's why… when I'm normally in classes I don't like, that's what I do, I just memorize everything, and I don't actually understand it, so when the class is over and I've gotten my grade, I forget everything, but I don't…
I: OK
S: So I don't want to do that here.
I: That's perfectly fine. Have you felt you needed to do that in bio classes before?
S: Yeah.
I: Are you taking any right now that seem like that?
S: Right now I'm taking cell biology, and I'm not really interested in cellular biology, so… but I'm trying to make myself actually really understand the material and not just memorize it, like I've done in past classes like genetics or animal diversity, so…
I: They have classes on animal diversity? That sounds pretty specialized.
S: I pretty much had to memorize every kingdom, every phylum, every species, everything like that of all the different animals, and uh… I could tell you, there could be yellow dinosaur, a little plastic dinosaur, and I'd have to tell you exactly what kind of species that was from. It was the least interesting class.
I: And you'd have to hope the dinosaur actually existed [yeah] and wasn't something like brontosaurus which was pieced together from a bunch of different dinosaurs. Well, that's unfortunate. I've had chemistry classes like that… in the second semester inorganic, it was kind of like that.
S: Oh no, me too.
I: You have to sort of remember what goes with what.

FCI specifics
I: Onto the specific thing. We gave you a couple of surveys, and this is one of them. The other one we gave you in class was more of an attitude sort of thing. I've actually given interviews based on this too, but that's not what we're worried about here. I showed you this, right?
S: Mmm-hmm.
I: You remember doing this?
S: Yeah.
I: You gave me some sort of disgusted sounding reaction?
S: [Laughs] Cause it was a pain in the butt to do.
I: In what way?
S: Just because it was long and there were a lot of questions… that was pretty much it.
I: Well, if it's any comfort to you, there's a concept survey that goes over roughly the same material but is about 50% longer.
S: Oh my gosh!
I: It's not just five choices. Some of them have nine or ten.
S: Wow.
I: So, if that makes you feel better, I guess I gave you the shorter one. Normally people just go through, and they take this, and they pick whatever answer they think is right, and that's what's typically been done. I should have brought along a copy of the instructions, but do you remember the instructions for this?
S: Yeah, it was to… circle what you thought was correct and put a square around the one you thought an expert would say.
I: That you thought a scientist would say, right [yes]… a scientist being a code word for expert in this case.
S: Yes.
I: Did that task seem like a reasonable one for you to do in this case?

S: Yeah, it did. The only thing I didn't like was that every time I thought an answer would be right, I figured that's what a scientist would say too, so a lot of them ended up being a circle and square around the same one.
I: Around the same one. OK, that's fine. So, let's actually… I mean, I looked through this before I talked to you.
S: [Laughs] OK.
I: Not while you were waiting in my office, but earlier this morning when I knew you were coming.
S: I'm sure I got a lot of them wrong.
I: Well, I'm not here to talk about or judge whether you got them right or wrong. We're gonna give this same thing at the end and see just to what extent people learned things in the class. That's why we give things like this. What you said… that most of your answers were a circle and square were the same, that's mostly right. A sample… can you read this one real quick here?
S: Yeah.
I: This is… "a stone dropped from the roof of a single story building to the surface of the earth." Look at your choices, and look what you picked.
S: I picked C, it speeds up because of an almost constant force of gravity acting upon it.
I: Mmm-hmm.
S: And I said the expert would say it speeds up as it falls because the gravitational attraction gets stronger (starts to laugh) as the stone gets closer to the earth.
I: OK.
S: I dunno.
I: All right, I mean, I don't know if you can… do you still think this? My first question is, of these five choices, why did you pick C for the one you believe?
S: Just… I guess I would say because I know that there's gravity, and that dropping it, it's going to fall. I'm not exactly sure why I picked that it would speed up all the time, cause I think I would have picked either A or C. A… it reaches a maximum speed quite soon after release and falls at a constant speed thereafter.
I: OK, so you were debating and circling picking A or C?
S: Yeah, I think so.
I: What's attractive about A?
S: Um, well, they're both kind of similar, cause it says they both… they both speed up to a certain point. A, I guess… (pause) A I would say because… I don't know if A is correct or not, but now that I've learned a little more about physics, and whatnot, I guess because now it says a constant speed thereafter [mmm-hmm], so I don't, I don't feel like you continuously speed up, you know, cause then by the time the stone hit the ground, it would be going really really fast, you know?
I: OK, so, right… that's a fine comment on the one you believe, and it's possible that can change, I was just wondering why you believe C. That sounded reasonable. What was attractive about choice B, then, for why an expert might pick that?
S: To be honest, I don't know why I picked that one. [Laughs] I don't think an expert would pick B anymore… (two people talking over one another…) the reason I picked it then…
I: Why… why not? Why don't you think they pick it now?
S: See, I don't know. That's one I was debating with myself over, cause I know that gravitation is stronger towards the center of the earth, you know, so it does get stronger.
I: How do you know that?
S: Common sense?
I: OK.
S: I've learned it over the years. That's right, right? You're making me question myself!
I: Comparing gravity near the surface of the earth with, say…
S: Ten feet up, yeah… that doesn't seem right.
I: OK.
S: All right, well, if I had to go now, I would say either A or C, I wouldn't say B anymore.
I: For the scientist answer?
S: Yeah.
I: Oh, OK. So, let me not get too far ahead of myself. You were about to make a guess as to why you thought it back then?
S: Yeah.

I: Well, go ahead then, in that case.
S: I don't know, I might have picked it just because it sounded very scientific (laughs) to be honest…
I: It sounded scientific in what way? Like, gravitational attraction…
S: Yeah.
I: Gravitational attraction gets considerably stronger…
S: Yeah (laughs)
I: OK. Well, that's OK. That's why it's an attractive answer. Some people pick that as the one they believe for whatever reason. Now… now, actually, do you think there'd be a difference between what you'd circle and what you'd square or not?
S: I wouldn't square B. As far as what I would circle… I might (pause). See, I'm still not sure which one I would circle. Based on common sense or based on what I'm learning? (hic) 'Scuse me. What do you mean? Which should I pick? Based on common sense, or based on what I'm learning?
I: Well, I guess that would be another question I'd ask you, then. If I were to ask you on this, pick an answer you believe… which of those strategies would you be more inclined to take? Would you prefer to answer what you're learning, or prefer to answer your common sense?
S: I would probably prefer to answer what I was learning.
I: OK, why do you prefer that?
S: Because at least with what I'm learning, I know what's correct and what's not, (did I even?) understand why things happen. What I've learned so far is that my common sense can be wrong! So, you know… what you think would happen doesn't all the time.
I: Oh. So… what you would answer as your belief now is kind of affected by your experiencing tutorial over the last couple weeks where you've been shown that your first intuition might not be correct?
S: Yeah.
I: OK. That's all right. We could go over all the other ones, I'm not gonna really do that, but you've made a comment before. You ended up with a bunch of them circling and squaring…?
S: Mmm-hmm.
I: Why do you think that happened a lot? You kind of already touched on it…
S: Just because, if, you know, I thought I was right, I figured that a scientist would think that as well, you know? I just figured that if I was answering something with what I thought was correct, I'm gonna answer it the way… it's almost like I'm gonna answer it the way a scientist would answer it, you know? So we'll say the same thing in the end. I don't know if that makes any sense.
I: So, you want to say the same thing as the expert?
S: Yes.
I: In the end?
S: Yes.
I: OK. That's fine too. I've seen that a lot on this. On this question you split, I don't know if you would still split these now, based on what you said. Is it… if you had one of these, would it be worrisome to you that the two answers are different?
S: What do you mean?
I: Well, if there was one answer that you really believe for whatever reason, and you had the impression from a previous physics class or whatever else that a scientist might say something different, would that be worrisome to you…? That there was a difference between those two things?
S: Yeah!
I: Why is that?
S: Well just because then I wouldn't know which was correct, or anything, and I'd wanna know which one was, you know? There can't be two different answers. Well, I know that… I know that there's two different ways… if you can explain things and support your answers, I know there can be two different answers, but I would prefer to be saying the same thing.
I: So, do you think if anything like this came up and you were talking to your physics TA or professor, do you think you could convince them to see your point of view?
S: Yeah.
I: In what sense?
S: Because if I pick something from my point of view, obviously I have reasons why I'm picking that. [uh-huh] So if I can support my answer with those reasons, then I should be able to hopefully convince you in the long run, and if not to convince you, at least to make you see where I'm coming

from, you know?
I: OK. That's useful for us, by the way, as TAs. I don't really know how specifically your section is going, but it's part of our job to actually figure out where you're coming from rather than to just look at the answer and quickly grade it in our head…
S: Yeah.
I: So, do you think then in these cases, the reverse could be true… that you could be convinced to see it the other way?
S: Oh, definitely.
I: OK. That happened recently? As early as an hour ago?
S: Yeah.
I: OK, that's fine. That's basically it, I think. There's one other thing. The thing you commented on these questions where you circled and squared the same thing… that's fine. Was there something different about this… this is the only question out of the thirty where there was a difference. I think so. Let me see (checks).
S: (laughs)
I: That's OK. I get dozens of these every time I give this out… I get dozens of these that have the same answer circled and squared on every question. Was there something different about this question that made you treat it differently from the others?
S: Maybe it's because I wasn't positive of my answer, so I thought maybe there would be two. Or maybe it's because… this is the worst reason ever to be doing that… you know how there was the option of putting which one would be circled and which one would be squared? So I might have picked two different ones just to make it so I had two different ones for a question, and not the same ones for every one. I mean, at this point, I didn't know I would pick the same ones.
I: No, you didn't.
S: That's probably the worst reason ever to do something like that.
I: Just because you were given the choice, you felt you should do it once?
S: (laughs) Yeah.
I: Well, whatever you think of that, if that's happening, I need to know.
S: You know, if you're given multiple choice, and it says "pick one if you think one's correct, but if you think more than one's correct, then indicate all those…" so you start looking for more than one to be correct.
I: Uh-huh.
S: It's just a train of thought, I guess, of being a student and trying to learn how teachers are gonna ask questions or… what they're gonna be looking for.
I: So this is part of the whole "game of taking the survey" even though… is that it? That doing this just once is part of taking the game of the survey just because we gave it to you as a choice?
S: (laughs) I dunno. Bet you nobody else would say that.
I: I wouldn't be surprised if they did, but I need to hear it…
(quick recap over something that happened earlier – and meaningless editorializing)
Final quote:

"My correctness matters when it comes to answering questions."
I: Even though your score doesn't…
S: Yes. It's a matter of how well I feel that I did… self-performance.
I: I guess that's often a healthy attitude.

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MPEX afterthought:

I: What did you think about the other one? The survey we gave you in class that was asking things like… 'understanding physics is just a question of finding the right equation to use… agree or disagree?'
S: OK.
I: Looking at a debate between two students and deciding which one of them you agree with. Did that seem kind of different to you?

S: Yeah, I thought it was an interesting survey. But I could see why you guys would ask us that, because you're trying to see… how many people are interested in just memorizing the facts versus understanding the concepts.
I: OK. Did you get a sense for the given questions there would be an answer we would wanna hear?
S: Yeah. You always do that automatically. If I had to pick, I would say that you guys… of course, you're gonna want us to understand stuff and not just memorize it, because it's physics, and you want us to be able to apply it to life.
I: Right.

Todd's interview

Interview: "Todd" for FCI survey
Interviewer: Tim McCaskey
Done on 10.21.03

Prelude

(idle chatter about how the interview money isn't mine and how that shouldn't affect people wanting to do an interview)

ed. note: Todd's test had a lot of writing on it that I didn't understand: marks on the page that sometimes indicated what he was thinking and such. That's why I asked about it.

Prelude and doodling

I: I'm gonna have a question about this. You marked the page, was there something you were doing to it specifically?
S: No, I was just scribbling.
I: Cause you've…
S: I doodle on a lot.
I: Yeah. It showed up a couple times, and I was wondering if there's anything compelling about that.
S: A lot of times when I'm thinking, like, a lot of times it helps if I'm doodling also, or maybe if…
I: We'll get to this later, but go on. What do you mean? This question 3…
S: A lot of time… I know this question, this answer is wrong, so I'll mark an X, and this is wrong, so I'll mark an X, and I think this is right, so I'll do a circle to remind. A lot of times, people will do it like a dot, a dot, a dot… I just…
I: So, there's nothing really special about this phrase?
S: No.
I: It's just, maybe that's right, so…
S: Yeah, it just happens to be where my hand was. Like, if you notice, when I do that, it tends to be in a straight line down.
I: OK. Huh.
S: Or, maybe I'm in the mood to make lines.
I: OK, all right. That's fine. I'm gonna get to this specific thing in a little bit

Background

I: But just some general stuff first, I guess. What year are you?
S: I'm a junior.
I: Majoring in what?
S: Psychology and biology.
I: OK, so why are you taking 121?
S: Um, it's required for premed, but also, like, I did really well in physics in high school, and I enjoy it, like, conceptually, it made some sense.

I: OK, all right, so, um, you're a premed, then?
S: Yeah.
I: And physics is required for that?
S: Yeah.
I: But you had physics in high school? [uh] just one year or two?
S: One year.
I: OK. You liked the class, you said?
S: Yeah.
I: Do you feel you got a lot out of it?
S: Um, yeah.
I: In what way? What did you like?
S: Well, especially at the beginning, cause I took it when I was a senior, and of course, people get senioritis in the last semester, so when we get to magnetism and stuff, I'm not gonna understand it as well as I do the basic laws of motion, like Newton's laws. That's pretty straightforward stuff to me. It makes sense.
I: OK.
S: Just how I learned it years ago.
I: But you thought the class was pretty good? Was it structured much differently than this one?
S: It was a really small high school, so there were six people in the class. People don't take AP classes in my high school, so there were six of us, and so…
I: Are you from Maryland?
S: Yeah. Southern Maryland.
I: Oh, in the south. OK. So, it was a small school? [yeah] But you liked the class. How is this class going for you?
S: Um (pause), it's going pretty well. Like, I understand most of what's going on. It's a bit… it's frustrating, I'm sure you've heard this from a lot of people, but it's kinda frustrating in the sense that, you know, especially with the lab stuff, I know you're… they're trying to grade on a curve, but a lot of people when we get 14s or 15s out of 20, nobody knows, 'is that good or not?' It's that whole doubt thing. We won't know anything until… or maybe he's already set a curve, but we don't know if a 14 or a 15 is good, seeing as nobody else is doing (pause)…
I: You're getting 14s or 15s now, or did you start out getting 14s and 15s?
S: 14s and 15s now. We were getting, like 13s and 14s before.
I: 13s and 14s to start is not so bad, at least it wasn't in my section, I mean, we try to grade as consistently as we can. The idea, at least, in my section, this is how we do this, you're in (ta's) section, right?
S: Yeah.
I: OK. Typically, what most of my groups will do is start out really low, some even below 13, and they'll just improve over the course of the year as they respond to my feedback.
S: Mmmhmm.
I: So, getting 13, 14, and 15 the whole semester long is not good, but starting out, and if you get better, then that's fine.
S: Well, a big problem that we have is the feedback we were getting, it's strange, because it's all positive. Like, you said this well. Three out of five.
I: And then you get, oh… that's not…
S: That's… I don't know why… I understand the difference between complimenting and constructive feedback [uh huh], and I don't feel that we're getting much constructive feedback.
I: Huh. OK. I mean, it should be constructive, but I haven't seen specifically what you get. Um, does the rest of it go OK, I mean, the tutorials?
S: Yeah, it's pretty straightforward. There's a lot of emphasis on understanding it, and not necessarily doing the math behind it.
I: OK. Um, do you… do you feel you're understanding some of the concepts that we present in the course?
S: As long as I've read the book beforehand [uh huh], like, I'm good with reading and understanding after I read something, and then if you go over it, then it'll make sense. A lot of times, if you go over it in class, either I'm too busy taking notes, or I have a… like, or I'm just confused about something.
I: OK. How do you know if you've understood something?

S: Um… (pause) good marks on the tests, exams… feedback…
I: So, you do it, and wait for feedback from us, and if it's favorable, then…
S: I think there's also a measure of, like, I feel that I understand… I'll understand Newton's third law if… not only I can recite it, but I can understand a situational context, you know? When I feel I can understand concepts without having to refer back to the notes, or something.
I: You mean, do a problem or write an essay about it?
S: Yeah, if I can do that.
I: Do an example, right?
S: A lot of times, you know, it's not only doing the example, a lot of times it's getting feedback on that also. And I'm really busy, I don't have time to go into the course center, to go into office hours [uh huh], but if I did, like, I love it when [PER prof] has, just before his exam, he has an evening where…
I: The question and answer session, right?
S: Yeah. That was really helpful, at least when I can make the time.
I: Did you go before this test?
S: Yeah.
I: The test go OK?
S: Yeah.
I: All right. You really liked the question and the answer session, right?
S: Mmmhmm.
I: OK, you saw that? I think the way he runs it is you ask questions, and he just answers them, is that true?
S: Yeah, pretty much, he goes through explaining it too.
I: OK. Do you find that different from how he normally does lectures and how we normally do…
S: I think when you guys normally do your lectures, you try to question more, and you don't necessarily provide the answer because you wanna leave the gap so that we can have an "aha" moment and realize it for ourselves. But I think…
(interruption by someone looking for another TA in the office)
S: It's true if that… I think that would work if you have a smaller setting, but when you've got a class of 200, I don't know how big our class…
I: 160 about, 170.
S: Not everybody is gonna be thinking actively and realizing [uh huh], so I just feel like a lot of times telling them straight out instead of making us think about it, cause that's… that's what we should be doing when we're at home doing our homework.
I: Oh, so you do that for yourself when you're doing your homework.
S: Yeah.
I: OK.
S: That's how (mumbles)
I: But you don't think this is useful for a large class, or tutorial even?
S: It has its merits, but not for a large class.

Expertise

I: OK. Completely separate question, not necessarily related to this class, although you can answer in the context of physics if you like. How do you know if someone is an expert at something? Or, how do you judge for yourself?
S: Define an expert. Um, in my… I took a psychology class where we asked that same question. Normally, um, somebody who's an expert has at least been involved with it in the field for at least ten years [ten years].
I: 341?
S: Yeah. Uh… 443.
I: Oh, OK.
S: At least ten years, and has a good background in it, and is an accepted authority in at least one or two realms.
I: How do you become an accepted authority?
S: In the world of physics, write a paper. Write a lot of papers. Go to Princeton.

I: (laughs) Well, (prof) is taken care of, I don't know about me. All right.
S: It's a start.
I: So, what does the psychology class… I mean, have you accepted this definition of expert you've heard in psychology class as your own, sort of?
S: We had a big discussion, and I just don't remember because it was a year ago, I don't remember the other conclusions that we came of, but there was a lot, like, I develop my own idea of what an expert is, but it was…
I: Which psychology class was this?
S: Psych 443.
I: Oh, I don't know what the numbers are.
S: Thinking and problem solving.
I: OK. The class I mentioned, 341, [mmmhmm] if you're a psychology major, maybe you've taken, it's the cognitive. Intro to cognitive.
S: Oh yeah, yeah, I did take that.
I: I took it, I forgot when, either last year or the year before, I'm getting old.
S: I took it last… not this past spring, but the spring before.
I: With (prof I had it with).
S: (name of his prof, someone else)
I: OK, different professor. So, I took that with a couple of people in this group because we're interested about cognitive psychology a little bit.
S: That's a good intro, if you really want to get into a lot of the more specifics, 443 really… I thought that was really helpful.
I: Really? I'm hesitant to mention it because my advisor might *make* me take it, but… he might want to sit in himself.
S: You take it in one of those computer labs in the plant sciences building (uh huh). They've got, I can't remember what they call em, course centers where every desk is a computer.
I: And you use the computers a lot in the course?
S: Yeah.
I: OK. So, you gave me this definition, that, I mean, you've come up with one for yourself for what an expert is. Have you ever seen experts disagreeing on something?
S: Mmmhmm.
I: OK, like what?
S: Um, I think years ago, what is it? Something about quantum physics… do quarks have mass, or… something that's not supposed to have mass.
I: Neutrinos, possibly?
S: Yeah, neutrinos, if they have mass or not. It's just more information or it's just a different interpretation of the same information.
I: OK, so what would you do in that case, if you were dealing with two experts giving you testimony on two sides of an issue, what do you do when they disagree? If you've got some people saying that neutrinos don't have mass, and some saying they do have mass. You maybe don't know much about neutrinos at all, how do you…?
S: Um, look at the background of the people, look at other factors, contributing factors to this whole debate/argument, like, I'm sure these people are not arguing in a vacuum. So, yeah. Look at a lot of other variables, not just the experts.
I: What else? Other peoples' perspectives on the argument, maybe?
S: Yeah, that would help. Look at what reason might this one expert be saying this, like, if he's a political advisor or something, what motives might he have, or if this is a professor at a college, and the college has a tradition of doing X, you know, what reason might this be?
I: When I, uh, when I talk about stuff like this to people, one of the things that comes up often times is politics. People claim to be political experts, and the responses I get from…
S: Well, political expert by definition has to be biased.
I: Oh.
S: In politics?
I: Right.
S: Almost.

I: So, I mean, say you have political experts. How do you decide between two of them? I mean, if you say both are biased, right? [mmmhmm]
S: Well, political experts, I never really cared, I mean, it's more one of those amusing things you just sit there and watch 'em go.
I: I think so too.
S: I really have no political aspirations, I guess. It's not…
I: Well, if you're OK with waffling on your opinion every couple of minutes, pandering to whatever's popular, then maybe politics is something good for you to do, but… I like laughing at it also. So that's the general stuff.

Survey start

I: This is the survey you did. Do you remember that instruction that we gave?
S: Yeah, and I remember having the difficulty because, you know, circle what I believe with what a scientist would say. A lot of these questions seem to be, like, if I were a scientist, I would… maybe I would know more or less, but since I'm not a scientist, I don't know what they'd say. So I would just… I'd just assume to say what a scientist would say. Which, um… that's why I circled and squared almost everything.
I: That's true, that's true. So, I guess that's one of my questions. Were there some of the questions on here where it made sense that we asked you to do this?
S: Anywhere where I circled something different.
I: I mean… you… I looked up your result (goes to look at his computer). You can look through that for just a second.
S: What do you mean "result"?
I: Um.
S: Oh, you graded it? Evaluated it?
I: I didn't… we're not grading this, this isn't for a grade, but what I did do… I'm sorry, I should have come up with the exact number before… if this thing feels like loading. We tallied up all the circles and tallied up all the squares.
S: The numbers, or, like, how many corresponded… A, B, C, D…
I: Well, not so much like that. (quieter: so, it's a 2) All right. We sort of give you a score for, you know, all the circle answers and for all the squared answers, and we counted the number of times that there was a difference. [mmmhmm] OK. Now, I just look here, and you… you did this twice apparently.
S: I only differed twice? I can believe that.
I: I think so. Well, why? Just because, for the reason you said earlier? That (mumbled) sure what a scientist would say?
(pause)
S: Let me think. Where did I differ?
I: Well, there are two. So, this is one.

11

I: 11. Along a frictionless path… so it refers to a previous question, in this, there's a hockey puck sliding along a frictionless surface, and at B you kick it, and… after you receive the kick (pause).
S: Oh, OK. (pause). I think… this is the one I initially wanted to answer, but then once I got to E, I realized, you know, if you're in motion, but there's… if you have no acceleration, then you're not having a force acting on you at that time. And I think it was confusion about, sort of, in a sense about the wording of the question, because the main forces acting on the puck *after* receiving the kick, so the kick is no longer being, in the process of being received, it's afterward.
I: Yes.
S: So, I think a scientist would say no forces, but I would say that… (pause) hm… Actually, I would say there's probably an upward and downward force. This is probably what a scientist should say.
I: A downward force… D, you mean? A downward force of gravity and an upward force exerted by the surface?
S: Is that true?

I: Now, that's what you would say now?
S: Yeah, just because, now that I've had the course.
I: OK. So, you'd circle it?
S: Yeah.
I: Would that get the square too [yeah], or would the square still go on…
S: Because I assume that when I circle [uh huh], that means it's the answer I think it should be. [OK] When I square, I think it's the correct answer, and if I don't know the correct answer, obviously I'll square what I circle, cause I'm trying to *get* to the correct answer.
I: OK.
S: So I would circle and square this one, then. Cause I'm trying, I'm trying to choose the correct answer, and I think a scientist would give the correct answer [mmmhmm], but if I don't know what it is…
I: So, you thought back here when you first took it that there's no force acting on the puck.
S: Yeah.
I: Or you thought a scientist might say that.
S: Yeah. And I wasn't… I just didn't know, I just wasn't familiar at the beginning of this course with those situations.
I: OK. Had you drawn in previous physics class, maybe, a free body diagram of something sliding on a frictionless surface?
S: I remember drawing it, and it's a lot like, you know, I remembered going through the process, like, I remember going through the process of, uh, you know, defining it (?) actually, but I don't remember the conclusions that we ever drew. Like, I know for the pendulum swing that we were doing in lab, I know there's, there is an equation, I just really… and I remember I always had a problem with the units of that equation [uh huh], but I never, I don't remember what it is.
I: The equation for what, like, the period of a pendulum?
S: The period of a pendulum, it's like T equals square root of… and then you've got gravity, and length.
I: Length and gravity. You can, just separate from this question, we'll just mention this, you can come up with it using dimensional analysis. You know there's T on the one side, and so that should be in seconds, and so whatever's on the other side needs to be in seconds too, and so you have l and g, right? What's l in, give a unit for that.
S: Meters.
I: And g is…
S: Meters per second squared.
I: Right, so we need seconds on the top, so you have to divide l by g, and that gives you seconds squared, so you take the square root of that. So the factor is root l over g.
S: That's a good idea.
I: That's what… I mean, so, there's also a constant in front. [mmmhmm], and the dimensional analysis can't tell you that, but what it can tell you is you know the units, so put the units together in a way that'll work.
S: Yeah.
I: We tried to do that in the first week, but its' not a lesson we've tried to bash into your heads over and over again.
S: Mmmhmm.
I: All right.

N3

I: The only other spot that explicitly had two different things is this one, with a truck colliding head on with a car.
S: Now, did I write this in myself?
I: You wrote that in yourself. So, you circled: the truck exerts a greater force on the car than the car exerts on the truck, and you added choice F and squared it, and said F = ma, we don't know how fast relatively either are going. So, um…
S: Yeah, I wasn't thinking about, you know, the net force.

I: First of all, do you still believe these answers, if you had this to do again, would you answer the same way?
S: Let me read it.
(pause)
S: I think I would circle and box E.
I: Circle and box E? So, why would you do that now?
S: Because now that, you know, we've gone through learning about forces, and it refreshed my mind, you know [uh huh], I think that, you know, it's the same amount of force. You can have… a different, differently massed objects responding with the same amount of force, equal and opposite [mmmhmm], but they'll just react with a different acceleration perhaps.
I: They'll just react differently. OK. [mmmhmm] So, um,
S: And for this one…
I: A, you mean?
S: I was, I was, basically I was trying to get the idea out that this is what, this is what I would think, this is what *anyone* would think, obviously, if you hadn't had physics. The truck is bigger, if a truck hits a car, it's going to go in the truck's direction.
I: And I see that intuition all the time, it's a very commonly chosen response. So, do you remember what was going on with this F here?
S: Uh, I think I was just happy that I happened to remember the equation.
I: Which one, just F=ma?
S: Yes.
I: OK. Um…
S: And, um, oh yeah, I thought that, I thought that how fast you were going would make a difference in terms of force, and…
I: It does, I think!
S: Yeah. Well, the magnitude of the force, but if they're equal and opposite, then they'll still be equal, right?
I: Right, well, right. For… when you saw that demonstration with the car hitting the truck, it wouldn't have mattered which hits which, or which is heavier, or how fast they're going. I mean, the force, the size of the forces would change, but it would still… right. So, you're right that the speed of the two things are, I mean, it does matter, but the F=ma just… you were just remembering? You were just remembering the formula and putting it down?
S: Yeah.
I: OK. So those were the only two there was a difference on.

Others

I: Now, the rest of them, you gave a reason for why… why circle and squaring the same one. I guess, let's see… I noticed a couple of times, you circled the word "frictionless," but given the story you told me about doodling on the exam…
S: Yeah, when I circled "frictionless," I did that on purpose because, you know, I just remember things are really different… I just remember the idea that things were really different when you come to friction.
I: So friction makes things kind of strange?
S: Yeah, and I just wanted to remind… like, I circled it so that I reminded myself.
I: Most of these are… I could go through a bunch of these and either you'd still believe them or you've changed your answer.
S: Probably.
I: Like, um, like this plane one. 14. You drop a bowling ball out of the plane, and the plane is flying in a horizontal direction, which path will the ball take after it drops?
(pause)
S: Is it this one? Um… or…
I: You circled and squared B, do you still think that's true?
S: No, because the bowling ball would still have the same x-velocity as the plane. [OK]. So, it would probably be D, or C. Um, you know, it'll keep going at that velocity, but then it'll accelerate to the ground.

I: So, are you not sure which one of those is right?
S: No, I'm not.
I: OK. (pause) How might you decide?
S: It's just the idea of the motion, and the ground, the ground's distance is changing (pause). I think it would be D, because imagine, if you dropped a bowling ball while the plane's going 300 miles per hour, but then the plane stops instantly, but right after the bowling ball is let out, the bowling ball is still going 300 miles per hour, but it's going at an arc motion down, so I guess I'd say D.
I: Oh, so if you could stop the plane, it wouldn't look like it's going straight, it would look like it arcs.
S: I think so, and I wasn't thinking that when I answered the…
I: Well, sure, sure. I guess it's worth it to see how your answer changes over time. OK. Right. Well, write on it, it doesn't matter. There was just one other one when I was reading this beforehand.

25

I: 25, you have a woman exerts a constant horizontal force on a big box, and the box moves across the floor at a constant speed. So… um, you only circled one.
S: I don't know why, but I should have boxed the ones that I circled.
I: You would have boxed the same one?
S: Yeah, I don't know why I didn't do that. Just bein' lazy.
I: Well, it was getting toward the end of the test, perhaps. I've seen this before all the time. This greater… OK, so, for this one, you circled that the horizontal force applied is greater than the weight of the box. Do you still think that's right?
S: Let me think (pause)… a constant horizontal.force…
(long pause)
S: It's at a constant speed. Um, if it's at a constant speed, it's zero acceleration.
I: Mmmhmm
S: So there'll be (pause) so, she is, she's exerting a force (pause) [mmmhmm], but there's gravity pushing back also. Friction. Um, this is something I'm still a bit confused about.
(pause)
S: I guess I would say C.
I: OK, but you're not sure?
S: No.
I: What else might it be? I mean, could you?
(interruption)
S: It could be this one.
I: Could be the same magnitude as the weight.
S: Well… it's probably different because… see, I never thought of using, you know, as to a weight being a force, I didn't really ever think about that [uhhuh], I guess weight is just mg, and force is mass times acceleration, and gravity is an acceleration, so let me think about that… So, as long as acceleration, then the question is… not necessarily F = W, but, um… is a equal to gravity? And I think acceleration… there is no acceleration, so it's less than gravity, so I would say F is not equal to W on that. Um. Is greater than the weight of the box? No, because we just said it's less. Has the same magnitude as the total force that resists the motion of the box? Well, you've got… (pause) you're force of the woman on the box and the force of friction on the box, then… and there's no acceleration [mmmhmm]... Yeah, I think that would be it. If the force applied by the woman is greater than the total force which resists the motion of the box, if the force is greater, then you'd be accelerating and not at constant speed [mmmhmm]. If it's greater than either the weight of the box or the total force, well, we know it's not that, cause it's not D, so I would say C.
I: So you would pick C. OK. Um, all right. So, you worked it out, OK. I think that's all I wanted to ask, so we've gone about half an hour, did you want any confirmation or to talk about any of the things I asked already?
S: Yeah, can you give me confirmation?
I: Well, I mean, I can't just say right or wrong, I can help you work it out.

Closure

I: This question about the plane, by the way [mmm]. Your intuition about it, if you stop the plane, it will look like it's going in an arc… that's basically right. Um, the way we would look at it perhaps is, right, this x velocity is constant, and you knew that. The y velocity is not [right] cause it starts out with no y velocity and it accelerates. So, the velocity starts out in the x direction and as it moves it goes down faster and faster and faster, so you're right for this.
S: OK.
I: You changed your answer, that's ok. This question, right, the acceleration was zero. You said that at the beginning.
S: Right.
I: So, you were comparing acceleration to gravity. That's fine, but the…
S: Is that an accurate way to think about it?
I: Well, acceleration equals zero means these two forces are the same. That's fine, right. That's right. So, C is correct here. W does equal mg, but it equals mg no matter what the acceleration of a person is.
S: Yeah, yeah, cause gravity doesn't depend on acceleration.
I: No, as long as you're on the surface of the earth, relatively speaking. So, I mean, this process was interesting, you going through all this, because you said way in the beginning and way at the end just before you made the conclusion that a is zero, and that gave you the answer.
S: Yeah, I wanted to talk about it.
I: Well that's fine, that's fine. So, both of the questions where you changed your answer that we've talked about, anyway, you changed it to the right one.
S: Mmmhmm.

Lian's interview: a brief check of the new split task

Interview: "Lian" for FCI survey
Interviewer: Tim McCaskey
Done on 3.16.04

Prelude

I: Let me first make sure this is recording.
S: Are you asking me, like…
I: I'm asking you what?
S: How is this gonna go?
I: How is this gonna go? So, like I advertised, some of the things I'm gonna ask are gonna be about this survey specifically [mmmhmm]. I wanna see if it's saying valuable stuff, like, are people interpreting the instructions in a way that's good, um… [ok].
S: OK, well, cause I know I got questions on that wrong, so.
I: I don't care! I'm not here to judge whether you got the stuff on this right or not, and I didn't come up with this survey [right], this has been around for a long time, and physics professors all over the place give it, but, uh, the task is kind of new, and I'm just seeing if this is a worthwhile task to give to people. First of all, actually, can you fill this in?
S: Yeah, sure.
I: It's just us guaranteeing that we won't sell your address to telemarketers.
S: OK. They can't call dorms anyway.
I: They can't what?
S: They can't call dorms anyway.
(pause)
I: I meant to… [yeah…] (pause) I'm kind of borrowing this office for interviews because the postdoc that was in here is now a professor somewhere else. [oh, OK] I'm surprised they haven't crammed four grad students into this office already.
(pause)

I: But anyway, so, this part, just talking about the survey items… only takes 15 or 20 minutes, and so for people that have an hour [yeah], I have questions to ask about your previous physics experience [OK], which, if you came here to vent, now's the time to do it. [OK] You sound eager.
S: No, well, not just… I dunno, I have a lot of cognitive dissonance over like, how the way I approach physics and stuff.
I: Cognitive dissonance? [*S: laughs*] I can tell I'm gonna love interviewing you. [OK] That sounds like something one of my bosses talks about at the group meetings: "we have a lot of cognitive dissonance in this group." Yeah. Anyway, the way this will go is that my questions about this (*referring to survey*) will be at the end.
S: OK, OK.
I: And before that, *cough*, I'm losing my voice. Background stuff about your physics experience to put this in context. Then I'm gonna ask a slew of questions about comparing 121 and 122 [mmmhmm]. Now, you didn't have [PER prof], did you?
S: I did not.
I: K, so you'll have a lot to say.
S: Yeah, definitely!

Background

I: So… there's the quick background stuff, then there's stuff comparing the two courses, and then there's stuff about this. So, that's how we'll take the time. If we need to go 'til 3, fine, if we end early, that's cool too. [OK]. But anyway, so, what year are you?
S: I'm a sophomore.
I: Sophomore? OK, yeah, our class is mostly juniors and seniors, did you manage to get in early?
S: I got a 5 on the AP chem. test, so I took orgo last year, I didn't take gen chem..
I: So normally you would have had to take orgo later?
S: This year, I would be taking organic this year, and then I would take physics next year, but I skipped the 100 level chem. classes.
I: Oh, that's a good deal. I took AP chem. in high school myself [yeah], but I was explicitly told by the teacher "my class will not prepare you for this test." And I was taking 5 or 6 AP tests as it was, so I didn't even take it, and I had to take the basic chemistry class, and I was bored to death.
S: Yeah… well, now I don't really remember my chemistry, it's kind of embarrassing. Yeah. So, I'm a little early with the prereqs.
I: So you're able to take physics now and not worry about it later?
S: Yeah.
I: That was a good idea. [*laughs*] It breaks my heart to see the seniors come in, they need this class to graduate, and they can't get in because the sections are full. [right] It ruins their day. Anyway, what major are you?
S: I'm zoology and Spanish.
I: (pause) OK, those are similar [*laughs*]
S: Yeah, that's the usual reaction from people, I don't know what I'm gonna do with them at all. (mumbled)
I: I knew some physics and history double majors.
S: Yeah. My friend is a neurophys and history major.
I: Neurophysiology?
S: Yeah.
I: Right. You don't know what you wanna do with that, these are just two things…?
S: I just like both of them. I declared Spanish last year, um, I mean last semester, but I came in a zoology major.
I: You came in as zoology? Are you a pre-med, or no?
S: I'm not.
I: You're not. So, this class is… required for zoology.
S: Yes, it is.
I: But not for Spanish, so much.
S: No.
I: I didn't think so. Yeah, *Fisica*.

S: *Si*.
I: I had two years in high school, you can tell the [lapse] the blazing proficiency.
S: Yeah.
I: I know one word. Did you have physics in high school before?
S: Yeah I did, in junior year.
I: Wait, so just one year only then, you didn't have AP senior year?
S: I took chem., so…
I: Makes sense. Um, when did you have 121?
S: Last semester.
I: Who with?
S: [name of professor].
I: OK. So, you're the second to third [professor] person I've talked to. How did that go?
S: It was… I don't know, I had a lot to complain about when he was teaching, and I… I mean, I went to all the classes, but they weren't that effective. I went, I just read the book and did all the problems in the book [yeah], and that usually helped me far more than his lectures. And his tests, I'm sure you've heard, they were just problems and problems and problems.
I: Well, any… [PERprof]'s are problems and problems and problems too.
S: Well, as in like, sort of, the kind that the textbook uses, like, if you can manipulate the formulas and, like, use numbers.
I: They all had numbers in 'em?
S: Yeah, all of them, definitely. I noticed the most striking thing in [PER prof]'s class is the lack of numbers, but [other professor] was very numbers focused [right]. His problems were very tough because they *weren't* just plug-and-chug, but we weren't prepared for them either.
I: Wait, [other professor]'s problems weren't all plug-and-chug?
S: They were… there was a heavy amount of manipulation. It was… the first two exams, they were very very hard, like, our TA was telling us he couldn't believe that Griffin put such hard problems on there. So, then the third one, he compensated, he had a ridiculously easy one that was plug-and-chug. (*ed. note: I think she only counts it as plug-and-chug if the given equation is already in some final form*) And the final was also sort of… they were…
I: F is 9 and m is 3, what is a?
S: Yeah, more or less, in the third one, everyone was just saying that was the simplest test. [Yeah] Because so many people complained, the curve was completely skewed to the right for the first two exams.
I: So it was a… what's it called, a one-tailed distribution cause it was very top-saturated, I guess (*referring to the 3rd test*).
S: Uh, bottom-saturated.
I: The easy one, it was…
S: Oh, yeah, well, no, no. It was…
I: Your averages for the other ones were more like 40%?
S: 25.
I: 25.
S: Yeah, and then the average for the third one was more normal, like, it was, it was probably 60, 70.
I: 70ish [yeah] OK. All right. Other than talking about specific, I mean, how else did the class go, were discussions useful?
S: We just sort of did problems in them. [yeah] I found that last semester, most of the time, I just studied by myself, and that was more effective than going to his lectures. It got to the point where I brought my book to lecture and took notes while he lectured and didn't really listen to him, and like, occasionally, I'd follow him and write something down, but the book… he went by the book.
I: I've heard the lecture attendance was like a quarter of the class.
S: It was bad. I was really sad for him.
I: You *went*, so that's more than…
S: But they weren't effective. If I had just sat there and taken notes, like he was very fast. The problem was that he messed up a lot on the board, so after a while, people were like, we don't know whether this is correct or not, and he could go back and erase half of it. Yeah.
I: [PER prof] doesn't mess up?
S: (*laughs*) Well, like…

I: I mean, I've known him for a couple of years, I know that's not true.
S: Well, not to the point where it was… it got in the way, and he wouldn't… he'd come up with the negative cosine and it was supposed to be sine, and he didn't know where he made the error, so he'd spend time, like, our class would just be sitting there, he'd sort of be retracing his steps, and looking at where he made the error, and we'd all be like very… oh, what's going on?
I: He didn't get a ping pong ball thrown at him?
S: No.
I: Should have gotten a ping pong ball thrown at him.
S: Yeah. [Right] But yeah, I liked his approach with problems more than with [PER prof]'s class. I don't know. The fact that… I don't really know how to say this, but I've been thinking about it, because, now that I'm in [PER prof]'s class, I can see some good stuff about Griffin, like, his emphasis on, maybe numbers and things.
I: You'd like to see more numbers in our course?
S: Yeah, maybe more straightforward ones, like, balanced with the conceptual, because it's so conceptually heavy right now [yeah] and, so it feels like any preparation I do with the book doesn't necessarily help me, cause the book was my… I got through it, I understood it, and the book helped me pass [other prof]'s class, but now when I read the book in [PER prof]'s class, it doesn't necessarily help me, and I wish it did.
I: Oh, so the book doesn't help you as much? OK, you'll get… you'll revisit some of these thoughts again as we go into specific parts of the class. So, what, so what did you feel you needed to do to do well in 121 last time?
S: Um, read the book, I dunno. Also, one thing is, uh, my dad's an engineer, so he always helps me. Like, last semester, he started helping me, he's helping me this semester. Um, and so, every time I had a problem, he would have the answer.
I: Do you live around here [yeah], or is this a phone thing?
S: I go home every weekend, not for physics, but I just ended up, "hey dad, can you look at this for me real fast?" and he'd just do it. So over the weekends, I just do physics. Not… I don't just do physics, I mean, I go home for other stuff.
I: That was last semester?
S: And this semester. I have, I teach over the weekends, and have piano lessons, so, I just go home and then when I come home, we just do physics.
I: What do you teach?
S: I teach English to Chinese students.
I: Oh, OK.
S: It's just an outside thing, and it brings me home every weekend, and he does physics with me.
I: What sort of engineer is he?
S: He's an electrical engineer.
I: So, does he like all these batteries questions?
S: It's child's play for him, it's very embarrassing how I get stuck at everything.
I: Right. OK, so, you talked about reading the book for [other prof]'s class last semester. What do you think you need to do in this class to do well in it?
S: Well, that's part of the problem, I'm not really sure. Let's see. Like… (pause) it's, I do, I use my dad as the main source of help when I don't understand something, because he always knows the answer. So, I may look in the book first, and then if I really can't figure it out, I just… I really just ask my dad. So I guess it's a little bit different for me because I have a resource that's so closeby, and he's an excellent teacher.
I: Sure. OK. Do you use the course center at all?
S: I don't. Having a group… I wrote on the survey at the very beginning of class, would you prefer to have a group where somebody definitely knows the answer [yeah], or where all of you try to figure out one. I don't like the 'figuring out one' at all [right], because in discussion, it's, I don't really like it that much, because… I mean, I do, because there's always someone who has a different approach and that turns out to be right, but it feels like a waste of time to me if all of us are sort of like, you know, edging toward an answer we all *think* is right, but, you know, if it's not right, then it feels like it didn't make any difference. [Right] So, I dunno, having a bunch of people who sort of don't know what to do together, it doesn't accomplish anything, I think.

I: Um, OK. So, you say you have a resource for dealing with homework [right]. I mean, what about studying for tests? How do you know what you need to do to do well on them?
S: I have a friend I study with, like, we do homework together as well [OK]. Like, when I don't ask my dad, we try to figure it out, and if not, then I have physics major friends here. So, there's always like, I guess, I always depend on someone who definitely knows the answer [got it]. Yeah, I like knowing that he or she is right.
I: How'd the test go for you?
S: I didn't do very well, and I was disappointed about that.
I: You did worse than you thought?
S: Much worse. [laughs]
I: So, you thought you did well, and came back…
S: Yeah. I think I got docked a lot for things, I dunno, the estimation problem, I thought, I mean, I didn't really… I wasn't sure what I was supposed to write. I got, you know, minus four for not explaining where I got my estimation from, and then… I dunno, I thought it was reasonable. The density was stated right there, so I just converted units and they said 'explain' and I didn't explain adequately for… in their opinion, so… And I made a lot of silly errors on my part, so…
I: Doing a makeup?
S: No. I don't think I would do better.
I: No regrades either?
S: I don't know whether I can have a regrade, because… there's no legitimate, I don't really have, like, something on which to say, 'you should give me points back.' I lost them, and I don't think I should have lost that many, but if they did the same for everybody.
I: Right.
S: But I am worried about my grade now.
I: Right, so you're not so sure what you need to do to do better here?
S: I don't know. It's just very frustrating when I don't… I can, I have the resources, but when it comes down to exams and I need to, like, know things myself [yeah] I guess I don't, and that's disappointing for me. I just feel like, I don't know, with physics, because I don't necessarily need to use it heavily, I don't anticipate doing that in my career. I think having a resource or having the knowledge that… having the resource and having people who know the answer, I think that'll be sufficient.
I: For you?
S: Yeah. And I'm happy… I'm happy knowing that once I knew the material, and I have the notes to prove that I did, and I can go back and access them as reference [right]. I really, really wish I had more of a sense toward it, but if it comes down to this, and I don't need to know circuits in everyday life, then I'm OK with not totally knowing the material. Later. Like, for now, I really want to know it [sure], and one other thing about the book is that they have a lot of, you know, sort of real life applications. That always interests me so much. That really [mmmhmm] attracts me, because, they have stuff like why do you slide on your seat when the car turns, stuff like that, you know, stuff about bulbs and how Christmas lights work, things like that.
I: You like that stuff?
S: Yeah, definitely. Because, then I'm like wow, you know, what I'm learning isn't problems. It has… people use this, and, you know, in thermo, we had something about in a car engine, how… geez, I don't remember, how water is used to cool this part of it, and then it heats up, and then, the cycle… how people harness these things, I think that's amazing, so I love reading about those.
I: Right, OK. So, stuff you're doing now isn't appealing to that curious side of you?
S: Not as much, yeah. I just like to know how things work, I suppose.
I: There are whole courses that talk about stuff like that. There's a book called "How Things Work."
S: Right, exactly! I've looked (at that?)
I: You've seen it before?
S: Mmmhmm, right.
I: Whole courses, they're often called "physics for poets" cause they're not mathematical [yeah, yeah], but they get at stuff like that [right]. Maybe you'd like it, but still won't change the zoology requirement.
S: That's true.
I: So, you talked about this a little bit, but how is tutorial going for you overall?

S: It's ok, I think, um, well, the part I like most about the course so far is analogies, the way he sort of explains… he explained current to us in a way that I can understand [mmmhmm]. Tutorial, I… it's a little frustrating sometimes how, you know, the TAs are like, they can't really give us the answer straight up but keep edging around it and stuff. But, I think, I think the tutorial and the sheets that we do are helpful.
I: You're TA's…
S: Matt?
I: Not giving you a straight answer?
S: Well, he really shouldn't, I understand, but it's kind of hard to be like, no, but here's the way to do it!
I: Good job, Matt.
S: No, I like him, I think he does a good job.
I: Right. Was it something that took a lot of getting used to for you?
S: Yeah, yeah. I dunno, I just think that… I hope they're not… inside, they're like, wow, it's staring them in the face and they really can't get it, so, I dunno.
I: No, I don't think that's the case at all, I mean, this is hard stuff, and the tutorials are long enough that you can't even finish them all the time.
S: Yeah, we've never finished 'em before. [right] But I dunno, it depends on whose definition of hard it is, obviously, it's second nature, I'm sure it is, for all of you. Here we are, trying to poke around and figure things out, and, I dunno. Once I get it, it's like "duh," but…
I: Well, everything is like that, right? It's hard until you get it and then it's "duh," right? [S *laughs*] Do you feel comfortable with them now, or more comfortable doing them now?
S: I still don't like defending the wrong answer, I really hate that. If, you know, somebody says "what I think is this" and I say "I think it's this," I'd really like to know if I'm right quickly before saying, oh, you know, I think it's this, and this, and it turns out I'm wrong, and I feel really stupid.
I: You don't like defending your answer until you know it's right?
S: Yeah, exactly. I don't like being wrong! I mean, cause in physics, it's, you know, this has been proved, and it's quite established that something is right or wrong, I'd like to know the right answer, and then why it's right.
I: OK. Um, have you ever, I mean, you've done this before when you defended an answer and it was wrong?
S: Yeah.
I: Was there anything right inside?
S: But it was… it was based on, the logic was evidently wrong at some point, so…
I: At some point, right. Part of the trick is to, when you think of something wrong, not just completely throw it out, but realize what part of it is right [yeah] and what part of it is wrong, and then at least you're convinced you got something right.
S: Right, but then I'll be like, then why wasn't I right? I dunno. The thing is, on exams, the question does come down to are you right or wrong, [mmmhmm] then, you know, that's when it counts, and I'd prefer to be right on an exam.
I: So, what do you see as the point of tutorials, then?
S: Um, I think just tossing around ideas [OK]. Like, he… he always finds some situation or some way to word the problem so that it's not obvious, and [right], just discussing with people is sort of helpful, yeah.
I: OK. Have they been helpful to you so far in any way?
S: I think they have. They sort of… sometimes… the current, the one, I think we did it last week, probably, hooking things up in parallel and series [yeah], when you hooked it up, you saw that it was dimmer or whatever. Overall…
I: How was that helpful for you?
S: Oh, just seeing it, not just circuit diagrams on paper. Theoretically, you know, resistance is one half and current is twice as much, so…
(pause)
I: OK. Were you about to make a general comment before I interrupted?
S: I don't remember (laughs)
I: You started to say something in general, and I said all right, well, what about that current one, how did it help? (mumbled)

S: Yeah, I think I did.
I: Can you think of ways that these haven't been helpful for you, then?
S: Um, (pause) uh, in… I remember the pulse one where he flicked it at different, different speeds, *nobody* could… nobody could tell just by looking whether or not the amount of time it takes to flick it up and down contributes to the speed of the wave. And I happened to know, I had the equation before, the speed on a wave of the string, and so I was telling people. I had my notes out, and this other TA came and told me to put them away, because that wasn't the point of the tutorial, so I was like, OK. It was hard to see it just from… you could tell why people would think that the flicker would cause a stronger wave.
I: Right. When… they changed the tension then, right?
S: Yeah.
I: Then, did the flick…?
S: Then, it was obvious.
I: That was obvious?
S: Yeah.
I: And when you looked at the point in the center, that was obvious?
S: Yeah, but… I could just as well have said when he flicked it faster or slower, like, it looks faster, without changing the tension.
I: But it wasn't obvious.
S: It wasn't, no. It was more obvious when they changed the tension, but…
I: With that equipment, that's all we can do. [Yeah] I mean, people, most people when we go up to them and ask them is the fast flick or the slow flick gonna go down quicker, they'll say, it's obviously the fast flick, and not only that, it should be, it should be blatantly clear.
S: Right, right. So, if I didn't know this equation, then, you know, I'd be like "of course it is", but… it's sort of false, like, I'm right, but you couldn't… not by seeing it, you know, just cause I happen to know this equation. If I didn't, then…
I: What that demonstration does, at least I hope, is for people that don't have the equaion and they think one will be faster, show them that it's not quite so obvious that it is. That demo shows you some obvious cases where something is faster, and it's obvious. But the one where you were sure at the beginning it is faster, it's not as obvious.
S: Well, nobody could really tell whether it was faster or not, so…
I: I grant that it was hard, right?
S: Yeah, yeah, so…
I: I'm not saying the tutorial was perfect.
S: So you could tell your intuition in that case, it didn't, you know…
I: Now, you pointed out that there was a big difference between first and second semesters as far as how the class was taught [mmmhmm]. Does the material seem significantly different?
S: I think so, I mean, it's part of the curriculum. You know, you move from Newtonian to electromagnetism stuff, and just the concepts…
I: Does it seem the same kind of thing to you, or significantly different in some way?
S: Um, well, he always finds ways to connect, you know, when we're dealing with forces, um, that has a direct connection to what we learned. But overall, I'd say it's different. Like electricity, you can really compare it with, like… you know, thermo. We haven't really connected last years, last semester's units, (garbled) law with motion, with what we're doing now.
I: You did thermodynamics last?
S: We did thermo, we did wave… we did wave motion, actually, like, the first part.
I: A little bit of what we covered?
S: Yeah.
I: We didn't get to the waves.
S: OK, yeah, cause the first one was sort of repeating for me. Then we did force, work, energy, friction… so, not much of that is repeated in the electricity we're doing now.
I: OK. So, other than the differences between the professors and their style of exams, you don't have to study for the material any differently?
S: Like, I don't really know how else to study besides looking at the formulas, knowing what they mean, and reading the book, and looking at the homework. I mean, I think that's universal for most of my classes [mmmhmm]. And I went to the review session, and it helped.

I: The review session helped?
S: Yeah.
I: Did he answer questions directly in the review session?
S: Um… I think more than he usually does, he didn't toss back questions at us, he just said "it's like this, it's like this."
I: Yeah, he's good about that.
S: Yeah. (pause) But he's still sort of confused a little bit… of us, some of us, because when he was going over wave motion, he was tossing, you know, omegas and ks and vs and stuff.
I: Throw a ping pong ball at him. [S laughs] Bring your own, don't leave it up to [TA], he's not gonna… he's not gonna do it.
S: Wait, when do people throw ping pong balls at him?
I: [TA]'s job as head TA is to throw a ping pong ball at [PER prof] if it looks like he's going too crazy with mathematics. [Oh] So, if he spends several minutes in a row with his back to you working on equations, he's supposed to get a ping pong ball strike from the side of the room.

Math comments

S: Yeah. I mean, I grant it that it's hard to teach physics without math. My math is not very strong right now, I haven't touched it since I took AP junior year of high school, so…
I: AP what? Calc?
S: Yeah.
I: So you had calculus?
S: Ages ago. I think, I really want to relearn it, because I think at that time, I really didn't know what I was doing [mmmhmm], and it's so useful for physics, and I really… my math foundation is like not existent right now, I just haven't touched it.
I: Do you think it would be useful in this class?
S: I think so.
I: Calculus?
S: Definitely.
I: Why's that?
S: Because some of the equations, they're just so much easier if you take derivatives and integrals. Like, I barely know, I barely know any of them right now, but like, you know, last week's homework is "why is the electric field the negative derivative of velocity, and somebody showed me, like, you can take, like, dv/dx and stuff, and it works, and I was like "wow, you're right. You just don't have to, like, solve equations."
I: You were trying to translate… this was a circuit thing?
S: No, it was in a homework, draw… graph the electric field as the charge travels along the circuit.
I: Along the *circuit.*
S: Right, right.
I: OK, I was trying to think if it was one I've graded before, and it is.
S: I got a point off because I didn't explain enough, so… (*laughs*)
I: Sure, you need to explain.
S: Yeah.
I: Um, so…
S: I don't know, I mean, like…
I: E is something like dv/dx, or it turned out being something like that.
S: I don't remember what it was. Because it was like V = Ed, then, something, I don't remember. If you have, like… cause V is, like, you know, the distance over time, or, the energy over time if you move (garble) dx, and you can move variables around. Anyway, I just thought sometimes… I wish I were more… I were, how do you say this? (pause) more familiar with calc than I am right now. I just haven't used it in so long, I think it would help me a lot. It's hard to teach physics and circumvent the mathematics part.
I: Right. Even though we don't require calc, a lot of the ideas require [right] concepts that are calc-like, you know, taking small changes and then taking the limit as it goes to zero. [right right] It's how you get velocity.

S: Yeah, so, I mean, I'm sure that the people who are familiar with calc have an advantage in the class, so…
I: Really? OK. Well, most of the class has taken calc before [right], like you. None of them are comfortable with it, or at least I've found this largely the case.
S: Yeah, otherwise I'd be in 142 instead of this, so…

Test woes

I: Maybe they just want to take the easiest physics. [yeah] All right. How would you recommend changing our course, then? I mean, this could go into anything now that you haven't mentioned already.
S: Like… hm… the test, the format was very surprising to me. I mean, I did… I thought… the problems that were the more unorthodox one… are you OK?
I: Yeah, I'm fine, I'm a little sick. (*ed. note: I was sick.*)
S: Yeah. The estimation one and the essay one, I thought… those were the ones I thought I'd done well on, but I lost a lot of points on those [mmmhmm]. And…
I: So what was surprising about the format? I mean, you've seen estimation and essays on your homework.
S: Right, well, I just did what I usually do for them, and got deducted a lot for the estimation, a couple for the essay, and… I dunno. Like, (pause) I dunno if I can say anything constructive about it, just some parts of it, like, I guess… I have done well in the base of what he's done (*garbled by I's cough*) and stuff. Cause I haven't been able to do homework by myself, and I'm sure that's what he expects, but…
I: No.
S: No?
I: No. He encourages groupwork for that reason. [Yeah] People can do it by themselves…
S: I haven't been able to, I mean, I don't… it is frustrating when people look at it and know how to do it, and… I couldn't come up with it by myself.
I: Right.
S: And so… if I'm the one being tested, then I really should know how to do it. [Mmmhmm] Well, I dunno, I think… he has, he has great intentions, but somehow they don't seem to work on me. I don't know if it's just me or… cause I was pretty disappointed when I saw the test score, so…

Attitude about class / "cognitive dissonance"

I: All right. At the beginning you mentioned something about having cognitive dissonance with the class.
S: Oh yeah, yeah!
I: Did you get at that yet, or… what did you mean by that?
S: That was, yeah… good, good segue. Yeah. I really *want* to like physics, you know? Cause I think it's so much more, it's more fundamental than, like, chemistry. I liked orgo when I took it [sure], but looking at physics, it's the groundwork for all the chemical theory and everything. And like, you know, what people have done (unintelligible) that's really inspirational, but I… I can't do it, and I'm mostly really mad at myself for not being able to do it, and I really really want to do it, but at the same time, I get fed up with it when I can't. I'm like, "ah, I don't wanna hate this, but right now I really, really do."
I: You're discouraged with the class at the moment?
S: Yeah, you could say that. And I really don't want to be, I mean, I try to be interested in it. My brother, who, he's on campus, he's like, "Irene, if you don't like it, don't like it." But I think it's a waste of time if you spend three hours in class and a lot more in homework and… and don't want to invest anything in it. I just don't like it when people say, "oh, this class is a waste of time." Cause you have to take it anyway, so [yeah] I might as well, like, you know, I'll try to like it, I'll try to not view it as a hurdle or something, it's very positive, whatever, thinking. But… (*laughs*)
I: It's a good thing to try to be.
S: I really really want to like it, it's just frustrating when I can't do it. [Mmmhmm] And, I mean, that's why I'm hanging onto the little real life applications, and like, "this is really cool, I mean, I can

see how it affects me."
I: Trying not to get completely disgruntled?
S: More or less, yeah. So, I dunno. When my dad explains something or when we figure something out, it's always a good feeling, so… [Mmmhmm] yeah. But I just wanna know the right answers to.
I: (*laughs*) Good luck getting them from him.
S: Yeah. I hope I can do better in the class, I mean, I'm doing OK, but, um… I suppose like another reason is, you know, my dad has a personal investment in it, and so I feel more pressure from him. Cause I'm never pressured by my parents about my grades, they know I can do fine, but in this case, you know, because it's what he did for a living, I'd feel so bad if I'm like… try and taint the class, and he'd be like, "Oh my God," or something.
I: Oh, this specific one with electrical stuff in it, you mean?
S: Oh, no, all physics, cause he knows all of physics.
I: He knows… he knows all of physics?
S: Yeah.
I: Does he have a degree or something?
S: No, he's just amazing at it, so…
I: Probably had to take a fair bit of it, I'm sure.
S: Oh yeah, definitely.
I: Electrical engineers need to take advanced electromagnetism courses [right], and those aren't a picnic.
S: Right, yeah. So, yeah, that's like… that's my, I mean, maybe that's a little unique individual situation, but… I dunno, for most classes I tend, I tend to, like, have this "please like the class" approach, you know? Otherwise, I get… I don't want to view class as a waste of time. So far, I've been lucky.
I: Three or so levels above the class you're in right now is the electromagnetism course they teach in grad school here, and in that, I was completely worthless, or at least felt it. All positive attitude attitude about physics [*S laughs*] went out the window.
S: Oh, I'm sorry.
I: It's just a matter of, it's just a matter of when it happens.
S: Yeah.
I: Early on, or do you go through a couple years thinking you're good at it, and then you discover you're not.
S: Oh, geez. That's not good. (*ed note: the previous exchange wasn't all that serious, the interviewer was not really depressed at this point, and S moved on quickly.*)
S: So, I think after physics, cause it's a prereq and I had to take it, the rest after these, I can take whatever life sciences courses I want to take, and I'm already interested in those. Physics, you know, I didn't really choose to take.

Recommendations on changing the class

I: So, is it hopeless, I mean, do you think there's anything the class can do or change that would make you sort of less frustrated, or do you just wanna do better?
S: I wanna do better, and, like, yeah… something about the… the wrong/right answer thing, it always bugs me. I dunno. See, I know it's not *right* of me to be like, "please give me the right answer [mmmhmm] so I can, you know, I'll know how to do it" you know? Cause he does it in a very roundabout way coming through the back door, like, this is how people figured it out… and I appreciate that, but sometimes I just want to know how to do it, and, yeah.
I: Right. OK. Well, was that all the, was that all the, uh…
S: Cognitive dissonance part?
I: Well, all of that or anything else you wanted to comment about the course? Cause that was all I wanted to ask you, I think.
S: Um, I dunno. Yeah, I realize what I said was pretty inconclusive, cause I don't know quite how to…
I: Not at all. Not everyone knows how to… what's needed to do well in this class, especially if you're new at it, so… I thought what you said was pretty honest as far as what's frustrating [right] and so on.
S: I just wanna do better in this class. Like, I'm middling right now, and, and I like doing well, but…

I: Yeah, I know the feeling. I was a student once too. Technically still am.
S: Yeah.
I: (*quietly*) I'm never gonna be done.
S: Aww. Side note from the interview.
I: I'm gonna put that on the transcript too. Do you hear me, advisor?
S: OK.
I: It doesn't matter.

The survey itself

I: Anyway, you remember doing this at the beginning.
S: (*frustratedly?*) Yeah, I did.
I: Why the long face?
S: Because I know, cause most of the time I ended up circling and squaring/boxing the same answer, and I'd be like, "well, this should be intuition, so it should be right."
I: Sure.
S: And a lot of them weren't, so…
I: That's… so, you did this a lot of times when there was a difference between your intuition and the scientist answer.
S: Yeah. And, well, I remember the first one, the dropping two objects. Intuition-wise, of course, the heavy object would drop, but I knew this one too well, so I didn't write that. I know that's right, but intuition-wise, I should have written something different like the heavier object would drop faster. So that's just a matter of pride, "look, I really know what I'm talking about, so…"
I: Oh, really?
S: The first one, the first one… the rest I was like, uh, I'm not sure about…
I: Yeah.
S: Yeah.
I: All right. So, I guess, what I'm gonna do is look for a couple ones with this difference. 'Cause when there's a difference, I mean… what? (*responding to some face S made*)
S: Wait, do I need to know the right answers?
I: No, absolutely not. All I wanna know is why you chose the one you circled, right? Why did that one make intuitive sense, and how did you pick the scientist answer also.
S: OK.
I: Whether they're right or not, you'll see what I ask you doesn't matter whether they're right or not, and I can… I mean, toward the very end I could go over some of them with you if you really need the reassurance. [S: *laughs*] I don't wanna ruin your attitude toward physics interviewing if physics has already been sort of tainted a bit.
S: Oh.
(pause)

Two metal balls question

I: So, the two metal balls in the previous problem [OK], so one weighs twice as much as the other. They roll off the horizontal table at the same speed.
S: Right. Um, I was using F=ma here. If one's heavier, it should have less acceleration. But then in the middle I was like, "wait, should that be the case for that?" [Mmmhmm] And then, but like you cancel the m's here somehow…
I: Wait, so this F=ma solution, which of these does it correspond to, the A you squared or the B you circled?
S: B circled.
I: So the heavier one…
S: Because if you have the same force, then the more massive one, cause, you know, quantity-wise, the product has to be the same.
I: And it'll accelerate less?
S: Right.

I: OK, so that's why the heavier ball ends up half the distance. [Yeah] So why did you think the scientist would both hit the same, then, if you used…
S: Because I was thinking of this one (*points to the above problem*)
I: You were trying to be consistent with number one!
S: Yeah.
I: Oh, gotcha, OK.
S: But then I couldn't figure out, I was like, "well, if I use this reasoning, then how come distance…" so, I was like, "oh, nevermind, I'll just circle that one."
I: That's a good thing to notice. I mean, often, being consistent gets you points on exams.
S: Yeah.
I: Especially on multiple choice. You can… I've graded ones where there were six parts and a student got only one out of the six right, so that would only be worth five. But the rest of the answers were so internally consistent that she got 20 or 25 points on the question [uhhuh]. It was amazing. Anyway, though, so, there's a difference, I mean, your intuition tells you B, and your scientist's answer tells you A.
S: Wait, was scientist the box one?
I: Scientist is the box, yeah. Here's a copy of the instructions (*gives one to her*)
S: OK.
I: So, circle is the one that makes the most intuitive sense, and the square's the scientist.
S: I think I reversed it in this case, then, or like, this was also based on from scientific reasoning, I just used F=ma.
I: Yes.
S: Um, but I think, this is a specific case because I wasn't sure how to explain it if, like, this one didn't correspond with it, so…
I: OK, so however the circle and square goes, I'm not sure how you wanna do that now, maybe circle A, square B…
S: I dunno.
I: Is it worrisome to you that there's a difference between those two answers, cause those two answers contradict.
S: Yeah (*laughs*). I realize that.
I: Yeah.
S: I think it was just… cause looking at that and looking at number one, like I said, I was like, aw, shoot. I know this is true, you know, like, it's been pounded into my head, but I forget how to explain it [uhhuh], so then I was like, well, maybe it follows the same principle, but at the same time, I recognize F=ma for this, so I'll just circle both of them.
(pause)
I: OK, now… there's a difference between the two answers, would the existence of this difference affect how you study this topic for a test?
(pause)
S: Um, I think I would mostly concentrate on the equation itself. You know, F=ma, and then, like, you know, one possibility, but when others get thrown at me, that's where I'm like uh, I'm not sure.
I: Oh, cause you're convinced that that's the right scientist answer, and…
S: I think so, like, it's… if I have a formula, like I know it's right. The only thing that trip… the one that, the thing that tripped me up was like if F=ma didn't quite apply for the first one, I didn't really know how it works. You know…
I: I mean, after I go through a couple of these, we can spend the last five or ten minutes or so talking about…
S: I'm sorry, am I not answering the question?
I: No, you did answer the question, but, I'm just asking…
S: … There's a discrepancy between these two, and so, um…
I: And so you… tell me if I got this right. In studying for it, you'd concentrate on getting the scientist answer right by focusing on some sort of equation.
S: Yeah

Question 4

I: …based reasoning. OK. Let's look at another one. I love looking at 4 because questions like this people differ between what makes sense to them and what the scientist… and don't laugh, it's not a symptom of something bad, most… most… a majority of students do it, and ones that end up getting all these questions right at the end of our class last semester often started out like this. So, a truck collides head-on with a car, a small car, so during the collision you said that the truck exerts a greater force on the car than the car exerts on the truck.
S: Oh, I didn't know, like, if they were going the same acceleration or, like… hm…
I: I mean, does that answer make sense to you?
S: Well, with Newton's like 3rd law, you know, the opposite and equal force [yeah], but if the truck were going the greater acceleration, then its mass times acceleration would be greater, so then the force would be greater than the one the small car had at the time of the collision. So, I wasn't sure like, so after seeing(?)… if you look at two bodies colliding, they have the same, equal balanced(?) but if the larger truck had a greater mass and a greater acceleration, then you would exert a greater force.
I: Do you think the larger truck has a greater mass and a greater acceleration?
S: Well, if it's a large truck, it's just given, I mean, we assume it has a larger mass, but then… it didn't really say, like, you could have been like, the car could have been like puttering along and then it came careening into it, so…
I: Yeah.
S: Then, in that case, I think… oh, well, like, shoot! So now… (pause) if it had a greater mass and a greater acceleration, then, I think that the force it exerted… but like, the one… the little car pushed back would have to be the same, I guess, but then it goes backward more because the mass is less.
I: So after all of that, is this the answer, A the one you choose… makes the most intuitive sense?
S: I don't know anymore. Now, I wanna say this one… because, shoot, I dunno. Because of Newton's 3rd law, but I dunno… (pause) like… huh.
I: Right. So, since you're having trouble thinking of something to say, I'm gonna try and be devil's advocate
S: oh no
I: And try to give similar reasons… or just different reasons for the same answers you picked. Newton's third law would say E, and so I'm gonna pick that as my scientist answer, cause I heard in physics class that the forces are equal and opposite.
S: Mmmhmm.
I: Um (pause) however, the truck is big, and it smashes the car, so it has to exert a greater force on the car, so that's the one that makes intuitive sense. So I would square and circle the same ones that are squared and circled on your paper here. Is that a worrisome difference?
S: Yeah, that's pretty much how I was thinking about it.
I: OK, cause it sounded like you were starting off thinking about it like that, but you changed your mind a couple times when you were talking about it, so… maybe I'm…
S: Yeah, but I still haven't been able to reach a conclusion…
I: OK.
S: (garbled) it doesn't leave a right answer, so…
I: So, wait, you're bothered cause you don't know…
S: Which one, what the case is, I mean, cause it's obviously one of those, so… (pause)
I: So…
S: Not, well, I think it's this one because, like, otherwise, you know, the force of the truck on the car should equal the force of the car on the truck.
I: Why?
S: What?
I: Why?
S: Because (pause) like, where, um… because then we'll, then, afterwards, like, the smaller car like accelerates farther backwards because it has the smaller mass [mmmhmm], so, I think then that that would account for why… why things happen.
I: So the car's acceleration is greater?
S: After it smashes, I think. Because I mean, like, when it goes backwards it goes… the acceleration backwards, like, the amount it's thrown back is greater than like, how much the truck goes backwards, because the car has smaller mass.
I: Sure.

S: So that one makes sense.
I: Oh, OK, so (pause) I mean, sounds like you've resolved it.
S: I think so.
I: OK.
(long pause)
I: I just wanted to see what kind of other… I love these kinds of questions.

Question 15

I: Anyway, so, here's one where… 15… a truck is broken down and the car is pushing it. And the car is pushing the truck, and it's speeding up.
S: Mmmhmm.
I: So, what's going on? You have circled and squared the same thing. The force the car pushes on the truck is greater than that which the truck pushes on the car.
S: Because, if there's net movement, then the force in this direction overcomes the resistive force of the truck.
I: Oh, ok. So…
S: Like…
I: Your intuition agrees with the scientist answer.
S: It's like dragging a box, we did some of those, I mean, like, you have force of friction and your applied force has to be greater than the frictional force in order for there to be net movement.
I: Movement from rest [yeah] you mean. Now, suppose I gave

END OF SIDE 1

BEGIN SIDE 2

I: Thanks for making sure I checked. OK, so this is recording now. So… back what we were talking about. You had C circled and squared, but I gave an argument from someone else that maybe I have this inkling in the back of my head [right] that A is right cause it's Newton's Third Law.
S: Um…
I: So do… I mean, do I need to study for this sort of thing on a test differently cause I… I split my answers and you didn't?
S: Well, I mean, then… the Fnet would be zero here, but you want an Fnet that's… greater than zero, so that there's a… results in a movement in that direction.
I: Oh. So you think there's just some way, if you just explain to me what Fnet is then I'll see the error of my ways and be convinced that C is right?
S: (quietly) What do you mean? (pause) Like, I mean, because usually for this, the forces would cancel and [yeah] but here, one force has to be greater in order for the movement to occur.

#16

I: OK, all right. Um, is the same thing going on for 16? The car reaches a constant cruising speed, the car is still pushing the truck, but they're both going at constant speed now.
S: Oh man, I need my notebook (*laughs*). Let me see.
I: Do you still think the car pushing on the truck has to be greater than the truck pushing on the car (pause)?
S: Hmm. There's no more acceleration. I'm not sure anymore. [OK] I mean, there's still net movement going on [yeah], so I would think that you'd still have to exert some force on it to make it continue moving.
I: OK.
S: Yeah.
(pause while I looks for a new question)

Elevator question

I: All right. One other type of question… an elevator is being lifted up at constant speed by a cable. Neglect friction. So, forces on the elevator are such that. So, you have the same answer A picked.
S: Mmmhmm.
I: How did you decide that that's the one that made sense to you?
S: Well, if it's being lifted upwards, then it's overcoming the force of gravity, I mean, the tension in the cable must be greater than gravity, otherwise… well, if it equaled gravity, it would just dangle there, and if it were less than, it would go down, it would hurtle downwards.
I: Mmmhmm.
S: But yeah, I think the force upwards has to overcome and be greater than gravity in order to maintain a net upward motion.
I: OK. Let me see if I can find another explicit difference. I don't think there are many more. OK.

Other stuff

I: Um, general question then. For the car/truck questions, for example, I'm just gonna use this as example cause we've talked about em a lot. You had a difference on one of them but not on the others. People have differences on the others. Now, suppose I gave this survey out, and it came back, and for people… every question that involved a car and a truck, they thought there was a big difference between which one made sense and which one the scientist answer was.
S: Uh huh.
I: Like say they went with Newton 3 for all of their scientist answers. Would the professor of the course need to change the way he lectured on that topic to fix this somehow?
S: Maybe by using those scenarios and explaining which one was correct. Like… I… see, I think I could just have… when you showed me the cable question [yeah], that was basically the same scenario as the car pushing [yeah] and so, cause if one thing is obvious, like it's not… the elevator question, you know, is kind of clear, because, you know, you can do vertical… one's vertical… free body diagram's easier. Yeah, so if you just said it's sort of like this, you know, to use an analogy and liken it to the situations, I think it would be easier for people to get.

Going over the questions

I: OK. All right. I think that's all the ones on this I wanted to ask, and since we only have five minutes anyway, we can talk about some of the ones… if it would make you feel better about it, I mean, I don't want you…
S: Are you (garbled) of this, or?
I: Well, I mean, would that make you feel better?
S: Yeah, it would.
I: All right. You should get something out of this, I guess. The reasoning you gave on 4, you started to agree with E [right] by saying the truck accelerates less than the car [uhhuh], and that's exactly what we do in tutorial. We have people… we give them a car/truck collision and we say how much speed the truck loses and ask how much speed does the car gain? Is it more or less?
S: They should be the same, right? Oh, no no… relative to the mass of the little car.
I: Oh, so wait, so the little car should do what?
S: It accelerates, like… the, the amount of speed that the car goes back is going to be decreased because of its mass, I guess [mmmhmm]. If its mass went to zero, the speed that it went at would be the same as the acceleration the truck was going at.
I: Well, OK, that's the way we get at it, I mean, you look at the accelerations so you have to look at how much the speed of the objects changes.
S: Right.
I: So the truck hits a car, will the truck's speed change very much?
S: Um… I don't think so, not as much as the car's speed will.
I: The car's speed will change more.
S: Right.
I: So it has more acceleration.
S: Oh, OK.
I: So the m and a compensate, and the forces are the same.

S: OK.
I: Right. If that wasn't obvious, don't worry, cause it took a whole tutorial last semester to get at that point [OK] for some people, but… that's how it works. Now, I mean, are you still uncomfortable about this ball-dropping thing?
S: It's just like the equation for it, I can't remember, it's like M1 M2 over R2, and then, like…
I: M1…
S: Or R squared, no no…
I: G M1 M2 over R squared?
S: Yeah.
I: All right. So, that tells the force of gravity between two objects, so what are M1 and M2?
S: The earth and the mass.
I: The earth and whatever mass.
S: Right.
I: All right, so…
S: You can cancel the mass of the earth, right?
I: Well, not really, but if you take the mass of the earth, and the gravitational constant, and the radius squared all together, you get little g. So the force of gravity is just little g, which is your 9.8 [right] times the mass of the object.
S: OK.
I: So if you have a heavy ball and a light ball, which of those feels a bigger force?
S: The heavier one.
I: Which one feels the bigger acceleration?
S: Cause if both of them are g, then, it should be, like… if the acceleration's defined as g in both of them, or multiples of g(?)
I: Yeah, I mean, OK, so the acceleration is g in both of them, but you get that from taking the mass times g dividing by the mass (laughs) so F over m.
S: Right. Oh! Then it cancels out.
I: So the mass cancels, yeah.
S: OK.
I: OK. Do you remember why a feather doesn't fall as fast?
S: Because of air resistance?
I: OK.
S: If it's in a vacuum, then it falls…
I: Then it would fall the same. OK, you remember that. This… this falling off a table thing.
S: I think the F = ma thing works, right?
I: OK, what F do you want to use?
S: The force with which you push them.
I: OK. This question doesn't have a force of push. It says… they roll off the table with the same speed.
S: Well, whatever you needed to, like, set them in motion.
I: So you needed more force to get the big one in motion, right?
S: (tentatively) OK.
I: OK, assuming you have that, and then they roll off at constant speed, how do you determine how far it hits?
S: Oh, so if… if the more massive one needed the greater force to set it in the first place [yeah] well, but then… if its mass is (pause) if it's mass is twice as great, then like the coefficients would cancel, right? (pause) If you multiply 2F = 2ma, it's sort of the same as F=ma. No it's not, because the a isn't… I don't even know. OK. Yeah. If a = F/m, then if you have a = 2F / 2m, then it cancels.
I: So they'll have the same acceleration.
S: Right.
I: And therefore what?
S: Therefore…
I: Will they hit the ground at the same spot?
S: (laughs) I guess so…
I: OK
S: Yeah.

I: OK. (pause) sure. There are two forces to be concerned about. You're more concerned with the one that pushed them in the first place.
S: Right.
I: Once they fall, only gravity affects it, but the argument is the same as for the first question, OK?
S: OK.
I: So, that's it. I don't have time to do…
S: Oh, no, you don't need to go over…
I: Yeah, yeah… I mean, not to do all of them [OK] but on all of these pushing questions, those forces are the same also.
S: *Really?*
I: Yeah.
S: Aww, geez!
I: Um, the trick is different though with this. You were saying for example if the forces were the same, they'd cancel, right?
S: Yeah.
I: What are the two forces you're talking about canceling?
S: Well, no, I was thinking like… the force of the truck pushing is inertia versus the car pushing it in motion.
I: The truck pushing on the car and the car pushing on the truck? [Yeah] Those cancel? OK. Those are equal and opposite, so if you add 'em, they add up to zero.
S: Right.
I: But the trick is, well, it's not really a trick, sort of looking at Newton 2, if I find… if I want to find the acceleration of something, I have to find the net force on it.
S: OK.
I: So if I want to find the net force on the truck, for example, what's the truck feeling?
S: The mass and the accleration of the car?
I: Well, it's getting pushed by the car.
S: Right.
I: Sure, and that's it. Maybe also friction, you have to overcome that or else you can't get it to roll. That's it. The forces don't cancel 'cause they act on different things. The force of the truck on the car acts on the car. The car is exerting its own force forward on itself. So the truck on car and car on truck don't act on the same thing. I mean it's tricky business.
S: Wait, so what's the answer? The forces…
I: The two are the same. They're just not the only two forces in the question.
S: OK.
I: The car is pushing itself along the ground, and you never considered that in this question.
S: OK, so that would be the one that's…
I: You have a pen?
S: Yeah. Was there some other force that I didn't account for?
I: Well, no! You have to… car… truck. The truck is getting pushed by the car. This is the car on the truck. This is the truck on the car. These are the same, but they act on different things (*ed note, no doubt I am drawing FBDs here*).
S: OK.
I: Because they're accelerating… this is accelerating the truck, and the car… there's another force on the car making it go. This beats that.
S: Right right right, OK. I get it.
(pause)
S: Man…
I: What?
S: Yeah, if you ask this on an exam, I get it wrong because I read these things wrong, so…
I: Right, but… so… whether you're right or wrong doesn't mean you didn't tell me anything useful about this, it doesn't matter, I can…
S: Well, no, but the worrying thing is that like on exams, the bottom line is whether you get it right [yeah]. So that's discouraging.
I: Maybe a little bit, but yeah, I mean, it's common. If your course was more problem-based, then you have experience doing that and not as much dealing with issues like this

S: Well, I mean, I meant to have some of that, yeah, you're right, but like… when it comes down to what's right or something, I'm not gonna be rewarded by my incorrect reasoning, so…
I: Well, in this class, you're rewarded a little bit for reasoning. More so than last time.
S: I don't know about that.
I: I mean, as long as you… you get maximum partial credit if you explain what you're doing…

END OF TAPE

Appendix D: Case study interview transcripts for "Patty"

Patty's interviews are included in their entirety here. The time markers were to help me keep track of the interview flow. I will introduce each interview by discussing which tutorial and topics were covered. [Aaron] and [Deena] (pseudonyms) are often Patty's groupmates. I have also removed the specific names of professors, only distinguishing them as physics education researchers when appropriate. Patty's instructor was Professor Q as mentioned in Chapter 4.

Interview 1: Background, a split task, and the motion graph tutorial

The first interview is longer than many of the others because we discuss background and the FCI split task. The epistemological point of the tutorial was discussing the benefit of catching and reflecting on mistakes.

(Time 0:00)
I: So, the couple things that we're going to go over are, um, a little bit of this, right, remember, from tutorial 1? And... this thing.
S: Oh yes.
I: That you did. Do you remember doing that?
S: Yes.
I: OK, so, I think I'll do this last, and then that one... this one in the middle, and I just have a coup... just so I know something about you, just some quick background things if you're ready to start on that. Um... what, uh, what major and year are you?
S: I'm a CMBG, cell biology molecular genetics junior.
I: I've heard that acronym before, but I never get it right. OK. Um... so, uh, are you premed or not?
S: I'm not premed, I'd like to work in a lab somewhere, I don't really want to be a doctor.
I: OK, so you want to work in a lab? What kind of lab?
S: Like, an experimentational lab, just... I mean, using stuff that I've learned, like, in the field of genetics.
(Time just after 1:00)
I: Have you done research before?
S: I'm actually currently working for the USDA, although this research we're doing is a little bit differently than my major. We're working with plants, and we're doing some experiments with, um, chocolate plants, actually, so... that's kind of cool, I can tell people I work with chocolate.
I: Tasty.
S: Yeah.
I: OK, so, um... so you want to do that when you get out?
S: Something like that.
I: So, uh, what are you taking this course for?
S: This is a requirement for my major.
I: For the major?

S: Mmmhmm.
I: And for all life science majors, too [yes], I think, right? Yeah, they all have to take this. Um...
S: I had a choice between 121 and 141. And I wasn't particularly interested in physics, so I took the easier one.
I: Uh, the easier one being the one with the lower number?
S: Well, I don't know, I talked to some people, and they said that... I don't know, maybe I should be in 141, but it, um, it seemed like they were pretty much the same as far as people... friends I have that had taken one or the other.
(Time just after 2:00)
I: OK. Um... uh, was there, was there a key difference that you heard about them that made you pick...?
S: Well, I heard... I don't know, I heard 141 had more calculus, and I said... first of all, I thought I'd take that one, because I thought physics without calculus would be a pain. But then they... I heard some other people said that 121 uses some calculus, and then I figured that maybe 141 would just use a lot more calculus, and... I mean, I know how to do calculus, but I don't particularly like it, so I thought...
I: So, um... so you've had calculus here, then?
S: Yes.
I: How much?
S: I went... I took, uh, up to calculus 2.
I: Up through 2?
S: Yeah, I just took 221.
I: Is this your first physics class, or did you have it in high school?
S: This is actually my first physics ever.
I: So you...
S: I never had it in high school.
I: You never had it in high school, but you've... but you've had calculus?
S: Yeah.
I: You don't like it, though?
S: Well, I don't know, a lot of it... a lot of it to me is common sense, and it seems like a subject that would be really easy that people like to make hard, so I figured, why take, you know, a harder course when they're going to, like, you know, go into little details that don't matter for me? I don't know.
(Time after 3:00)
I: You mean physics, or... or...?
S: Physics and calculus.
I: OK. So you... when you mentioned that it was, um... related to common sense, you said that about calculus, was I hearing that right?
S: Well, that's more physics than calculus, I suppose.
I: Oh, it's more physics? I mean, how do you... I mean if you haven't had physics before, then how do you think of it as being related to common sense?
S: Well, you drop a ball, and it falls due to gravity. I mean, that's physics, right?
I: Mmmhmm.
S: Motion and, I've... you know, like he said in lecture, I've lived for 20 years, I have a pretty good idea how things move. I mean, I don't know all the exact formulas for them. I know several of them, because I've taken calculus, but... it's... the little I know has been pretty much all common sense.
(Time just after 4:00)
I: OK. Um... so, so do you expect a lot of the stuff that you're gonna cover in class to relate to that common sense somehow, or have... do you have... have you heard, or do you have some reason to believe that it will disagree with your common sense a lot?
S: I have... I'm expecting it to agree with common sense. I'm sure there will be some things which are unusual that, like, you wouldn't think would happen, but in reality, they do, so... I don't know, maybe... maybe they are a little more difficult concepts to grasp, but as soon as you understand them, they become common sense. At least to me.
I: Hm. OK. Um...
S: I think it was... I don't know, was it... no, it was in your email, I liked that quote you had. That all physics is impossible or simple. Impossible when you don't understand it.

I: And then it bec... OK, uh, well, there's... right, so that's what the quote says. But, there's a difference... there's possibly a difference between something being easy and something being common sense.
(Editor's note: My email quote is attributed to Rutherford. It reads "All of physics is either impossible or trivial. It's impossible until you understand it, and then it becomes trivial.")
(Time after 5:00)
S: Mmmhmm.
I: Do you agree with that?
S: Definitely.
I: OK. So, I mean, we'll see. All right. I'm not... my place here isn't to make a whole commentary on what physics is supposed to be like. I mean, I'm supposed to... I want to get your opinion on that. And it might change throughout the semester, or it might stay the same. Um... so you didn't have... you didn't have physics in high school, but OK, you're in this now. Trying to... see if there's anything else I needed for background. I don't think so. So what I have here is the... the first survey you did. OK? Um...
S: Yeah, I did most of the same answers for things.
I: OK, so, right... so, the task we gave, you'll remember, you were asked to circle the answer that makes the most intuitive sense, and square the answer you think a scientist would give. Um, did that instruction make sense? Did it make sense to you that we were asking you to do that?
(Time after 6:00)
S: Yeah, it made sense. It did. It just... with the specific questions being asked, I don't know, like, some things, if you'd asked me the same thing years ago, like, when I was a child, I would have answered differently. But... I mean, it's still, maybe, some of the things I circled would have been intuitive, but since I know them for a fact to be... in my own, you know, just, living and doing stuff and even some experimental stuff in lab, maybe... but I know for a fact that that is... I know what's right, so my intuitive is now the same as what I think a scientist would guess.
I: Is it because you have more experience dealing with real world things and thinking about them?
S: Perhaps.
(Time 7:00)
I: Um, well, we have this thing now. Do you remember any of the questions from it that you think you might have answered differently when... back when you were a kid, to use your words?
S: Well, um... I don't know, like, there was the one question about dropping different weighted balls and which one would hit the ground first, or something like that. Was it different size, or different weight?
I: I think it's question one here, can you look at that?
S: Yeah, it was question one.
I: OK.
S: Um... let's see, yeah, they weighed different. The same size, but they weighed different.
I: Mmmhmm.
S: And, at first I would think that the heavier one would drop, but I think I remember hearing before that... they're the same. OK. Maybe I should have circled the other way for that, intuitively.
I: I mean... right now, though... so, so that's a valid thing. Is there a way that you make intuitive sense of this answer? I mean, you have some reason to believe that a scientist would say that the balls would hit at the same time.
S: Mmmhmm.
I: Do you have some intuitive reason for believing that's true now?
(Time just after 8:00)
S: That I've seen it happen, so... I don't know. It depends on your definition of intuitive, I suppose.
I: I mean, what did you think we meant by that when we asked you the question?
S: I don't know, you want me to take the test again?
I: Um...
S: As in, like, answer as in what you... when very first... in your lifetime when you heard this question, what would you have said at that time? Instead of what you... what you think now, I suppose.
I: Well, no, I guess I don't want you to take this again because, I mean, it was a long time ago, it would be very hard, and kind of... it sounds like kind of an artificial thing, right? Go back and think what you were like ten years ago, and answer these questions, I don't know how easy or even authentic

a task that would be. Um, maybe the thing to do is, then... I was gonna go over some of these. Like, you... there was a difference between the circle and the square on one of them, and so I'm gonna go over that. And then I'll pick some ones out where it's common for people to... to have a difference [right], and then... then, you know, we'll talk it out, we'll try to figure out what... what you meant by circles.
(Time long after 9:00)
S: I mean, I see the point of the test, that you wanted to point out that some things that seem like are this way, are actually when you look at, you know, all the laws and physics, they're actually this way, although it doesn't seem like that, wow, it is. And this is how the scientist would answer because that's how it's true. But, you know, the common person doesn't think that.
I: Um...
S: I don't know. I have actually... maybe I have taken a physics course, because I've taken astrophysics [mmmhmm], although that's an astronomy course and not a physics course...
I: Yeah.
S: It did have a lot of physics in it.
I: OK.
S: So, I would say I know more than the common person when it comes to physics as far as people who've never taken physics course.
I: Well, I can, um... I'll try to explain what this is for. A lot of people that come into our class have had physics before, or at least something like it, and, you know, you have too, so... even people that have had physics don't always do this, but... they remember a lot of the laws and the rules that they learned, but those rules don't make sense. Even now, even after they learn them.
(Time long after 10:00)
S: Mmm.
I: Um, and, you know, I'll show you some examples of that in a bit. And so... so, we give this at the beginning and the end of the semester because there might be a difference, uh... you know, at the beginning and the end, after you learn it through, you know, the classes in this department... uh, do you get more of the scientist's answers correct? Uh, do you get more or less agreement between the circles and the squares? That's the kind of thing we... we look... we look for. And everyone(?) responds to this in the same way, I've gotten tons... dozens of these where every answer is circled and squared the same. Um... so, each person's different, and...
S: Well, it's... I don't know, if you want to look at this from a student standpoint, too, what are we really learning from this test? I mean, I'm taking this course as a requirement, and to learn the material.
(Time just after 11:00)
I: Mmmhmm.
S: But from this, I don't know, the 15-20 minutes I took to take this test [mmmhmm], I really didn't learn anything. I mean, except for maybe... a way to think about life, which professors like to do all the time.
I: So... that's kind of, that's kind of unusual. Do you expect to learn things from... from taking a test?
S: Well, yeah.
I: Or... do you... I mean, this is just a survey, of course [right], it's not graded or anything like that, but... a lot of people see tests as, you know... us evaluating you.
S: Well, the test... the purpose of a test is to make sure you know the material. I mean, that's kind of what the definition of a test is. You learn something, and the only way for a professor to know whether you've learned it is to test you on it.
I: OK. I thought from your sentence what you meant was that you expected in the process of taking this test to learn something.
S: No, OK. This specific test...
I: Yes?
S: We just started this... the first day. So we haven't been taught anything.
(Time 12:00)
I: Exactly.
S: So we're taking a test on... nothing, you know? Just what we know in the past, kind of. Or what... what... this is just a survey to see what knowledge we have coming in to the course.
I: Somewhat.

S: OK, so... I mean, yeah, it's nice, but it doesn't really do anything as far as, like, my learning the material. I mean, maybe that's kind of a cynical way to look at it, but it's just... I don't know, if you want to get down to, like, you know... I'm paying to go to this school, and learn the material.
I: Yes.
S: And I'm... I'm not saying this is a bad thing at all. I'm just... maybe some reasons of why I did this because, like, if you circle/square everything, it only takes half the time, perhaps. And I don't see any real, uh, benefit for me doing this survey, except for to help you guys. Which I honestly... I tried to do, but maybe, you know, subconsciously, I was actually thinking, "this is a waste of time, this is a waste of time." So...
I: Oh, OK, so...
S: I'm sure several other students would have thought the same way.
(Time just after 13:00)
I: I'm sure they think it, and I'm glad you said it, right. So... I'm not worried about honesty from now on from you.
S: No, I will be very honest. I will try not to be rude.
I: Right, um... so, normally there wouldn't have been a lab this week anyway.
S: Right.
I: Um... so... I, I mean, you will only see this at the end. This is... so, you're right. I mean, have you taken tests in your other classes where in the course of taking it, you felt you learned something, or did those seem like evaluations, too?
S: Um, I've taken some evaluations, I mean, they, do them every semester kind of to check up on the teachers. But, um...
I: I mean evaluating you. I mean [oh], you feel like if you're taking a test, say, in a calculus class that you're learning something from the test, or they're just trying to see what you know?
S: Well, I'm also learning myself what I know. I mean, maybe I think I know the subject, and I take the test and I fail it, then I've learned that I obviously don't know this as well as I thought I did. The teacher also learns that, but in taking the test, I may have learned something about myself that I didn't know before.
(Time after 14:00)
I: Hmm.
S: And it's, you know, it's also... if you do know it, then you learn that you know it. That's the purpose of a test.
I: So if... if this helps you feel better about this...
S: OK.
I: Uh, we'll be giving it at the end, and... you know, after all this is over, I can give you a feel for what you... or, how you changed, and what you learned, and how you improved. If that's helpful.
S: OK. Perhaps.
I: Um, we give... I mean, there'll be plenty of tests throughout the course of the semester designed to show you how you're learning the stuff in the specific class. Uh, yeah, I mean, I would be lying if I said that this wasn't more for us. It's for, you know, improving the class and understanding how... how much people get out of it and how people are affected by the class.
S: Right. I mean, I realize that. I don't have a problem doing it.
I: Uh huh.
S: But during the actual process of doing it, I may be thinking, you know, like, this doesn't really matter so I'm not, you know, doing as well on it. I'm not taking as much time on it, you know? Just little factors like that, which... you know, I'm sure that's everyone.
(Time after 15:00)
I: These are... these are compliactions that always appear when you're doing stuff like this, so, um... I mean, that's part of the reason I... I talk to people, uh, about it. People are capable of telling me honestly that, you know, "I just decided to do the same thing for... whatever reason." Um... the old survey we gave out was slightly different, so... it'll still be useful to go over some of these.
S: OK.
I: So, uh, let's... hm. Let's just see. (pause) The only one you had a difference on was number 10. Um... you have a... the puck sliding with a constant speed, and then you suddenly kick it.
S: Mmmhmm.
I: Um... (pause)

(Time 16:00)
I: So, let's see. And the kick is in the direction of the arrow.
S: Mmmhmm.
I: All right, so... along the frictionless path you've chosen in question 8. So you, you chose a path. This one.
S: I choose that one, OK.
I: Um, so let's just clarify that one really quick. Um, why did choice E make sense? I mean, does it still make sense now when you look at it again?
S: Yeah, it was a tossup between A or E for me. I don't know, I guess it depends on how hard you kick it, cause if you kicked it just a little bit, then it would probably do that, but if you kicked it really hard... I dunno, maybe... maybe I thought E because even if you kicked it so hard it looked like A, it'd probably still be, like, a little bit slanted.
I: It would be a little bit slanted? OK. What's the diff...
S: Just my line of thinking.
I: Is there any... OK... is there any difference between E and B? Is there any reason you prefer E to B?
S: Well, yeah, you kicked it this way.
I: Yeah?
S: So, I mean... I don't know. It's just... the trajectory seemed to make more logical sense.
(Time after 17:00)
I: Um, how did it make sense? Do you know?
S: Well, it... if you... I dunno, just from playing sports and stuff, it seemed to do that instead of that. I don't know, maybe...
I: Like, oh, balls and pucks tend to curve sometimes?
S: Yeah. I don't know. I mean, all these were guesses, I really don't know any of them. I mean, there may be a few of them, but...
I: OK, um... so, along the path you chose, the speed after getting the kick [mmmhmm], see, you circled... decreases. Continuously decreases. [mmmhmm] And squared constant for a while, and then decreases thereafter.
S: Yeah, I guess the reason I was confused on that was cause it was frictionless, and... I said, continuously decreases, but then... I dunno, like... it just made more sense that it would continuously decrease, but in not knowing that much about it, I thought perhaps there could be some reason that E would also make sense.
(Time after 18:00)
I: So, um, I mean, you don't... you don't have to try to use any terminology or anything, but can you explain why... why it makes sense that it would decrease?
S: Well... if... if there was friction involved, then it would make a lot of sense, but I suppose because, I mean, you said frictionless [we did], but there's still gravity involved, perhaps, and maybe... did you say the forces of air or something like that was ignored or not? I mean, there's still other forces involved that could slow something down.
I: Forces exerted by the air are negligible.
S: OK, you did say that, but what about gravity?
I: There can still be gravity, so how might that affect things?
S: Well, I don't know, I just... maybe, I guess... gravity doesn't necessarily slow things down that are moving. I just... I... I think I was thinking along the lines of gravity. But it would just... it would have to stop sometime. But I suppose... I guess because I... I wasn't sure if there was a difference between if it was frictionless or if you were, like, in a vacuum in space, if there would be a difference between frictionless and space.
(Time after 19:00)
I: (whispered: frictionless and space) OK, um, now, choice E is the one you squared, so... is there... I mean, so, you had some common sense reason for picking C.
S: Mmmhmm.
I: Um... what's different about E that makes it more likely to be kind of the scientist / expert response?
S: I don't know. Now that I think about it more, I probably should have boxed A.
I: A? Uh... so, it's still different than C.
S: Yeah.
I: Why would you box A?

S: Just... if it's not... I guess, because if it's not going to start decreasing right away, then it would probably never decrease, so it would just remain constant.
(Time 20:00)
I: OK. Um... did that... so... so that's one explanation for why A might be right. That explanation doesn't make as much sense to you as C does right now?
S: Um... well, I would have to learn more exactly what frictionless does to objects in motion, because I'm used to living in a world with friction, so... I just... I didn't know. You know, if you were to kick a buck... a puck regularly, it would continually decrease because of friction and other forces. But... I don't know. I... I guess I circled C because that was what made perfect sense. And then... probably should have boxed A, though. Just thinking about it more.
I: I mean, C... C just relates to real world [right] experiences you've had, and...
S: Right, and because I've never had real world experiences in frictionless surfaces, then... I don't know.
I: Ever play air hockey?
S: Yeah, but I'm not very good at it.
(Time 21:00)
I: Who is?
S: But there is some friction still involved in that, isn't there?
I: Uh, probably, yeah.
S: But it's just (a lot less than normal?)...
I: You can't... yeah, right, that's the idea. If you... if you hit it, it won't... it just doesn't stop immediately, and that's the...
S: But it eventually stops.
I: Very true.
S: Is that because of friction, or because of something else?
I: Um, I will... I will... I will let you determine that later. Since I'm not affiliated with the course, I want, you know, any changes or improvements or learning that happens to be as independent of me as possible.
S: OK.
I: It's a hard thing to resist, cause I've taught this class so many times, my instinct is just... do it, explain it. [OK] But, I'll have to... I'll have to temporarily resist in some cases. Um, so, a lot of these... uh... you circled and squared the same thing, so, I'm just... I'm just gonna go over some popular ones. Uh, or at least ones I like to talk about with people. Um, if a large truck colliding head on with a small car... it's 4, right?
(Time after 22:00)
S: Mmmhmm.
I: During the collision, and you have five choices...
S: Right.
I: Um...
S: Well, but I circled and squared the same one because I didn't see a reason for any of the other four. I mean, there was one that kind of stood out. [w... wait] And that's what I did...
I: Wait, which one was that? That was A?
S: Yeah.
I: K, why... why did that particular one stand out to you?
S: Well, cause they're both having force, I mean... I mean, I didn't think the car had no force. And, it's... I mean, there are other factors here that we are not told, I mean, maybe the small compact car actually demolishes the truck because it's, like, some freak alloy metal that's super strong, I mean... or maybe it's going a lot faster or something like that. But logically, the large truck would smash the small car, so it would be having to have more force from the truck than the car.
I: So, how do you... how do you treat the word "force" in this question?
(Time just after 23:00)
S: Um, as, like, "strength," I suppose?
I: OK. So... so... the truck exerts, uh... hm...
S: Strength? Power?
I: See, how... how would I, how would I rephrase this to use that word? You can't exert... I guess you can exert strength, it just sounds a little funny.

S: Well, which one's stronger, I guess? I don't know.
I: And it makes sense that the truck [yeah] is stronger, so if... if they were to have sort of a "strength contest," it would win.
S: Yeah. But the... car still has... strength or force, power, whatever word you want to use, of its own. I... I didn't think it had zero force.
I: OK.
S: That's why I didn't put D.
I: You didn't put D. OK. Um, do you have any experience dealing... I mean, maybe you've seen this in astrophysics, dealing with Newton's Laws?
S: Uh, somewhat, yes.
I: OK, um... have... have you heard of the third one about... when two things exert forces on another, the forces are always equal and opposite?
(Time after 24:00)
S: Oh, that's right, yeah.
I: Mmmhmm.
S: Yeah, but... I thought that was only, like, things weren't moving.
I: Only if things were moving.
S: Only if they are moving?
I: No, I'm... I was just repeating what you said, and I said "weren't." (no, I didn't)
S: Oh, no, like... like, this bottle is doing the same amount of force on the desk, that's why they're not moving, cause they're... I mean, I may be remembering wrong, but it... I thought if they were exerting the same force, that there was no motion, because they were just kind of, you know, stuck together. Not moving.
I: All right, which... which forces are you comparing?
S: Things that aren't moving. Just anything. Two things that are touching each other that aren't moving.
I: Mmmhmm.
S: Two objects. But, um... like, yeah, but... as far as, like, Newton's law, isn't a lot of that force see, like, as far as... maybe I'm thinking... I don't know, I'm kind of combining chemistry and physics here, but, isn't a lot of that... can force be considered the... the heat of the crash? The, uh... the thing... the objects being thrown away from it?
(Time after 25:00)
I: Uh, well... um... you will... over the... I'll give us a chance... I mean, we're gonna be, if this is OK with you, of course, we're gonna be doing this... sort of going over the tutorials as you do them.
S: OK.
I: So we'll... we'll... we'll have... there's a tutorial devoted entirely to talking about subjects like this.
S: OK.
I: And when we get there, um, we can... you know, see what you took out of that rather than me trying to [OK] go over it too much now.
S: But the reason I... I... I guess the reason I did the same is cause I thought if they had... the only other one I would put there is if they had the same force. And I thought that was not the case because they would be motionless. So that's why I answered the way I did.
I: Um, so... if... if the truck exerted a force on the car equal to the car on the truck, then they wouldn't move?
S: Or they would, like, each sustain the same amount of damage to each other, I suppose.
(Time just after 26:00)
I: OK, sustain the same damage. Got it. All right, um... let's see.
S: Cause the way I see it, the truck's gonna pretty much run over the car.
I: Right. So, there's another one involving two things of different sizes, um... 28. So...
S: Pushing off each other.
I: Yeah, do you remember that? [mmmhmm] This picture? So A pushes off on B, and... and A is bigger. So... uh...
(pause)
S: Well, I didn't really see why that would matter, cause they were on wheels.
I: All right, so, look over what you said first.
S: Well... what'd I say for 28? E.

I: Circled and squared E for both.
S: Oh, they're not even moving there! Yeah, that's why I said that.
I: They're not moving. OK, the, uh...
S: Oh, during the push? Oh, maybe I read it too fast.
(Time 27:00)
I: And while the students are still touching. So, do you understand what's happening? A is pushing off on B?
S: Yeah, I understand what's happening.
I: So, I mean, can you describe... what do you think happens after... after that?
S: Um, well, they both go flying in separate directions.
I: In seperate directions, OK. Um... so, do you have the same answer now that... now that we've clarified the question? Or...
S: Let's see. During the push, while the students are still touching one another, this is before they actually start to move? I guess they'd move a little bit and still remain touching, cause his knees are bent.
I: While he's straightening his legs out, yeah.
S: Mmmhmm. Maybe I said they do the same because they'd each move about the same distance apart, I think. Unless his feet are touching the ground, that would slow him down.
I: OK. Same distance apart. All right. Um... along that same line... I think I'd... I've, I've... done a lot of talking about these questions and I'm not as quick at flipping between the test pages as I should be. Um... right.
(Time well after 28:00)
(pause)
I: Can you tell me what's going on in 15 here? You said C for both.
S: Mmmhmm.
I: And so, do you remember these questions? There was a car pushing a truck [right], and now, the car's pushing the truck, and the truck's in neutral or something, and... you're speeding.
S: Right, I said that the car would have more... force [OK], because he's pushing the truck, the truck's moving, the truck's not doing anything. I mean, if the truck was pushing force on the car, then I think they would be still or moving in the opposite direction.
I: So, OK, so... if somehow, this truck were exerting more force, it would... the whole mess would go [mmmhmm] backwards. OK. Um... all right. I'm gonna get off the car/truck ones. There's only one other, and it's similar. Um...
(pause)
(Time after 29:00)
I: I'm interested also in this... in this 17 question, where you have an elevator lifted by a cable.
S: Mmmhmm.
I: All right? So...
S: Yeah, I answered that one differently because...
I: What do you mean you answered it differently?
S: Well, I wasn't thinking along the same lines as, like, it's moving and the force, and, you know, depending on which way it's moving, and who's exerting more force... because the cable just was connected to whatever power it needed to to pull up the elevator. And, the whole... I mean... it just seemed like a completely different setup of the question, I could see the similarities between the first three we talked about, this one seemed really different.
I: So, it... it doesn't even seem like the word force should apply to this?
S: Not really.
I: To this question?
S: At least a... a different type of force, you know?
I: What? Can you elaborate? What do you mean?
(Time 30:00)
S: Well, the other ones, you were pushing, [mmmhmm] and something was moving.
I: Yes.
S: Well, here, you're pulling, which is a little bit different, but I... it's... the cable is also moving, and... I mean, maybe if you want to rephrase this question to say, like, the motor that's controlling the cable. But still, it still seems different because it's... it's pulling instead of pushing, I suppose.

I: OK, so... I mean... let's, let's... so, I appreciate your interpreting the wording that's there. Um, you've given a new one, so let's play with it. So, on... on this elevator, if it didn't have a cable, what would happen to it?
S: It would fall down due to gravity.
I: Presumably, so gravity would, gravity would... pull it down.
S: Right.
I: OK. Um... now, so let's say we have a motor up top, and it's pulling up.
S: OK.
I: Right? So... so treat those as the two things in this question you're comparing.
S: OK.
(Time 31:00)
I: If the... if the elevator's being lifted at constant speed, uh, you have gravity and you have the motor pulling up... can you consider that a force? Are you comfortable talking...?
S: It's still a different type of force than what we were talking about before, because we were talking about objects hitting each other.
I: Ah.
S: And the force was only, like, motion. And this time, we have, you know, a motor which has unlimited power, unlimited force because it's being given force by electricity or gas or whatever it's using. And it's... it's not moving, its force is not due to its size or its motion or its speed, it's due simply to the fact that it's powered and it has as much force as it needs.
I: OK, I think I see what you're saying. Um... let's see, what other... interesting things? (pause)
(Time 32:00)
I: Oh, so... maybe... maybe this will get at the same issue I was trying to talk about, but it's about real objects and pushing, so you might... you might feel more comfortable talking about it. 25. If a woman is exerting a constant force on a box, sort of pushing it along the floor, uh, it's at constant speed.
S: OK.
I: So can you, uh, look at the choices there and explain what... why choice D made sense to you?
S: Constant force... oh, I said cause the box is moving, so she had to be doing more force than the force that... keeps the b... or, she had to be pushing with more force than forces which prevent the box from moving, because it's moving.
I: So, so... she's gotta "win" somehow.
S: Right.
I: Or else it won't move.
S: That's what I thought, yeah.
I: K, uh...
(pause)
(Time 33:00)
I: So, so... you're fine talking about this in terms of forces because you can actually picture someone [yeah, I suppose] doing... doing the pushing, and all that. OK. Almost done with this side. This is a 90 minute tape. We won't use all the tape, in fact, this might not take the whole hour. You'll still get all of this (referring to the $10).
S: Oh, OK.
I: Uh... so... are you OK with doing this in future weeks?
S: That's fine.
I: Also? I think, depending on how the tutorials go, it might only require a half an hour each time... depending on the tutorials, but we'll see. I... I have a couple questions about this, and, uh...
S: OK.
I: So we'll switch to talking about this now. Um... (pause) so, on... I guess it's been a couple days since you've done it. On reflection, um... what did you think about all this stuff at the beginning talking about, uh... about mistake catching?
(Time 34:00)
S: I think it's a nice skill to have, but you kind of learn it very early in school, and it was kind of redundant to do it in college. I mean, it's... it's just things like, "oh yeah, I made a mistake" and learning why you made that mistake. And maybe you make more mistakes in physics because your perceptions on things were wrong, and you have to understand why they were wrong. But as far as having a whole thing on catching your mistakes, it just seems kind of juvenile to me.

I: It didn't make sense that we were asking you this question sort of at this point in your schooling?
S: Yeah, I guess so. Like, it's... it's a skill to have, yes, but, you know, by this time, I think you oughtta already have it.
I: Have it? What is the "it?"
S: Being able to catch your mistakes and know what you did wrong and understand things.
I: And know what you did wrong... OK, um. Let's see, did I...? I should have printed out... um... (pause)
(Time 35:00)
I: I thought I printed out the things that you all said, but I didn't. I guess... I... I... I wrote it down, uh, some comment you made about the mistake catching later on, and I'll talk about that when we get there. Um. So, so is... is to you... is what you get out of thinking about your mistakes just finding out where you make them?
S: Well you... you learn about... you learn about the problem more. I mean, it's kind of the old saying, you can learn more by losing, you know? And if you don't realize you lose, then you're not gonna learn anything. So if you make a mistake, you can... I mean, you learn more from it because you have to go back and do it again, you know? Practice is good. So... it's just... it's important to catch your mistakes for two reasons. If you don't, you'll get it wrong, and if you do, you'll learn more when you have to do it again.
(Time just after 36:00)
I: You'll have to do it again? OK. Um, there was a case where... hm... I'm just debating how to do this, because I'm... I'm new at talking about these tutorials. There might be an opportunity I have to actually just bring the tape and show you what I mean when I'm talking about specific instances. I don't... I don't know how freaky that will seem to see yourself, but... maybe we don't need it right now. Uh, you were talking about this question on... the distance graphs with your group. About what the... what it should look like, and, uh... you know. I think your prediction was something like this, [mmmhmm] and someone else in your group made a prediction like that.
S: Yeah, actually, I was the one who screwed up, and [Aaron] had it correct.
I: Oh, you... you made the wrong prediction?
S: Mmmhmm.
I: Oh, I thought... I thought you made the correct one.
S: Well, I did later, because I caught my mistake.
I: OK. Um... was... was talking about this helpful to you at all, now?
(Time just after 37:00)
S: Well, the fact that we made such an emphasis on catching my mistake...
I: Mmmhmm?
S: I would have still realized I did it wrong even if you hadn't made the emphasis on it, because we talked... [right] you know, the only... the thing that was handy was, you know, comparing with people and, you know, checking your answers against them, and I saw that [Aaron] had something different. And going back and looking at it again, I realized that I was wrong, and he was right, so...
I: So, actually, um, talking about the predictions before... doing the experiment was helpful?
S: Oh, you mean, it's just... having... oh! I guess, yeah.
I: What... what part, what part of this tutorial are you talking about, then? Your discussion with [Aaron]? Was this... was this...?
S: In the, uh, part 2 right here. Now compare your predictions.
I: So you, you made your prediction...
S: Mmmhmm.
I: and you claim you made the wrong prediction...
S: Mmmhmm.
I: and he made the right prediction and comparing them then was helpful.
(Time 38:00)
S: Yeah.
I: OK. But what... is that helpful... is that brand of helpfulness sort of... sort of independent of our [yes] focusing on mistakes? Like, you... you got something out of that, you would have gotten something whether we asked you about it or not?
S: As long as you had asked us to make predictions and compare them against each other, I think I would have gotten the exact same benefit out of... regardless if you had done the thing on catching

mistakes.
I: The whole section one?
S: Right.
I: OK.
S: Because, you know, students do that all the time. "What'd you get?" And then, "Oh! I messed up here." So... I'm used to doing that.
I: OK. Um... now, the predictions... you make... you made a prediction here, and while watching the tape, I saw... I think you actually did it upside down.
S: Did I?
I: Does that seem right?
S: I think I have my paper here.
I: You should... you should actually bring that. That's very helpful. Uh...
(Time just after 39:00)
S: It's pretty messy, cause... I wrote in pen.
I: I don't care. I'm messier.
S: Page 3. Yes, I did... I did write it wrong at first.
I: So you drew it upside down at first?
S: Yeah.
I: OK. And... and what helped you fix that mistake?
S: I think I saw my friend's papers and realized it, and then I reread it again.
I: You rewrote your prediction?
S: Yeah. Or... I don't... no. I know I reread it. I... I don't know if I reread it before or after I saw theirs. It was most likely after.
I: Reread what?
S: The, uh... right here.
I: Oh, the C.1 instruction? Predict the distance graph.
S: And then I compared it to what we'd done in the previous as far as which way was which.
I: Which way was which. So... so this helped you again here?
S: The comparing?
I: Yeah, comparing predictions and then... you ended up getting it right?
S: Mmmhmm.
I: OK... were there... I don't seem to remember this, but, um... were there any cases at all, you remember, where you came to an agreement as a group on something, and then there was something wrong with it?
(Time after 40:00)
S: No, I think we got it right every time.
I: That seems to be what I remember, too.
S: Because we were just doing really simple things that... I mean, walking towards is opposite of walking away. OK, we all understood that, we all got that. You know? Um... I think it was just, like, the first time where, you know, we were new to it, we maybe got it wrong. But after that, we understood it. There was usually one person, at least, in our group... usually three, often four that... we would all get it right.
I: So... after you did this [mmmhmm], you switched the axis from distance to velocity. You remember that?
S: Yes.
I: You clicked on a computer program?
S: Yes.
I: And the graph changed, right?
S: Right.
I: So what you ended up... what is it that you ended up with?
(Time just after 41:00)
S: We ended up with a graph showing velocity (times the distance?)
I: Of this same motion?
S: Um, yeah [I think it was]. Yeah, it was. Because we didn't do another reading. And we just clicked it right away. [Did] Yeah, that's a...
I: So... so I watched you do that. Right? It appeared, and you were explaining to one of your

groupmates, it was either [Deena] or the... girl sitting next to you.
S: [Annette] was...
I: [Annette] is her name?
S: Mmmhmm.
I: I didn't... I didn't hear that. I'm not talking to her about this, but I guess it's useful to know her name. You were talking to her about, um... the... the different parts of it.
S: Mmmhmm.
I: Right? Did that help with the whole rest of the tutorial at all? We didn't ask you to do it, so I'm just wondering if it helped you.
S: What did I talk about?
I: Well, what happened was, when you switched from... I brought... [right] I brought paper. When you switched, you had this, and the velocity graph that came up was something like this with a bunch of squiggles. Or zero [right], and down here, and you were explaining the parts of it.
(Time after 42:00)
S: Right.
I: Did it help you to talk that out, or was that just something you felt like you already got?
S: Oh, it always helps me to teach someone else.
I: OK.
S: I mean, I... had that my whole time in school. If I can explain something to another person, not only do they know, but by teaching, I learn it better myself.
I: OK.
S: So...
I: Um, all right, so... there was that, and then you had a checkout.
S: Yeah. It was messy because I didn't read the whole directions.
I: Oh, like where?
S: Well, it said to make any...
I: Smooth the bumps out?
S: Yeah, smooth the bumps out, I didn't...
I: OK, so you just redrew the line?
S: Yeah.
I: OK, so that... that's no big deal. I mean, this isn't graded, so...
S: Yeah, if it was graded, I would have gone back and...
I: Have you been... have you been able to find this tutorial book, by the way? Um, so you'll have... [yeah] for next week?
(Time just after 43:00)
S: Well, I got my one for another class. I don't think I've gotten it.
I: OK. Well, we'll try to have copies, but you should try to see if you can find it.
S: Yeah, I plan to go to the bookstore again before class.
I: Um, so... I think, actually, let me... I don't know how long...
end side 1
begin side 2
I: (in the middle of a sentence) these tutorials this week, and I'm ready to let it go. I spent a lot of the summer watching this stuff, too.
I: All right, we're going. So. Two other things. We asked a question at the end... uh, what one piece of advice would you give to students who want to avoid making mistakes in their velocity graphs?
S: Well...
I: OK, did... was that question helpful at all? I mean, was it helpful, like, um... like comparing the graphs was, or was it something you saw as less helpful like, um... the stuff on the first page?
(Time just after 44:00)
S: I saw it as something less helpful.
I: Like this?
S: Yeah.
I: OK. Um...
S: Just because...
I: You have, OK... so, you have written, see, "know the differences between velocity, speed, slope, direction, time, distance." Let me go over the things that I wrote down that your group said verbally.

Uh, you said something that, "doing experiments and paying attention to common sense are important," do you remember saying that?
S: Mmmhmm.
I: OK. Uh, can you elaborate on... on the common sense aspect of it? You might not see the question as useful, [OK] but I... I still want to see what you think about the...
S: Well, it just... the things I wrote down here: velocity and speed, you know... if you walk faster, you will cover more distance in less time. I know that from common sense and real world experimentation, if I... if I walk faster, which is speed and velocity, I cover more distance, less time, so it's just simple things like that... and the fact that, you know, the relations between velocity and speed...
(Time just after 45:00)
I: So what kind of mistake might someone make who forgets about that lesson?
S: Well, someone who forgets the difference between velocity and speed could quite easily just graph everything on the positive side when they forget that when you're walking in different directions, it affects your velocity.
I: That it should be negative?
S: Right.
I: During those parts? OK. Um... another person in your group, I think it was [Aaron], actually, mentioned that reading the directions...
S: Yeah, that too, I should have written that.
I: I mean, you don't have to write it, but you agree with that?
S: I do, because I actually did make a couple of mistakes because I didn't read the whole directions. Like, I forgot to smooth the bumps out in my graphs, so I had a squiggled line instead of a straight line.
I: So you're not gonna have to be... I'm pretty sure if you're ever asked questions like this on a test, at least, if your tests are anything like ours were, and I think they will be, um... you won't have to worry about things like bumps. [OK] But, but... considering... I mean, looking at the problem statement carefully could be very helpful. Um... all right. So, that's the last thing about mistakes. Uh... you actually, toward the very end, when the TA was pressing you, uh, about, you know, what you learned from it, and, uh... and how velocity and distance are connected... uh, you mentioned some calculus.
(Time well after 46:00)
S: Well, yeah, because, I... I've known that velocity is the derivative of position, and acceleration is the derivative of velocity. That's something I learned in calculus.
I: Mmmhmm.
S: And then he commented, like, "whoa, whoa! You don't have to know calculus for this class."
I: After that, he said something like, "just kidding," right? And, uh...
S: Well...
I: It's true. Um... so, here's a stat for you. 90 or 95 percent, or even more of this class has taken calculus.
S: Has taken?
I: Has taken it.
S: OK, that's good.
I: So, your concern at the time, I mean, you said something... you were wondering if you were taking the wrong thing...
S: Well, yeah, because...
I: wrong section...
(Time 47:00)
S: I don't particularly like calculus [mmmhmm], but it's a very useful shortcut to have when doing things like physics.
I: Shortcut? Uh...
S: Well, I took a stat class where we didn't use any calculus at all, and it was a lot of tediousness. And then later, I learned the calculus formulas that would have been very helpful in that class [yeah], and it made a lot of the calculations a lot less time-consuming. And I could understand them cause I knew calculus, and I thought if you did physics without calculus, it would... it would be similar to that stat class I had taken.
I: So, do you think the calculus knowledge... I mean, so, it's clear you have some, I mean, everything you describe about... between distance, velocity, and acceleration is right.
S: OK.

I: Um, does it... I mean, is it more of a shortcut in helping you get the graphs right, or do you think you actually understand the stuff better, now that you've seen calculus and... have that in your toolbox, so to speak?
S: It's probably more of a shortcut [mmmhmm], but I feel I understand it.
(Time just after 48:00)
I: OK. Would you have more trouble, I mean, describing the relationship between distance and velocity without being able to use terms like "derivative?"
S: Probably, I'd have to think back what other words were for it. Perhaps. Well, I guess I wouldn't have, like, difficulty, but... just, the word "derivative" would be at the tip of my mind and preventing myself from saying that, I would have to catch myself, I suppose.
I: Well, OK. You don't have to prevent yourself from saying it, um... just, I mean, be prepared in your group to deal with people who... like you, don't like calculus. I mean, they probably have taken it, I don't know what their math backgrounds are, but... anyway, in case someone asks you. You say you didn't like calculus much?
S: Well, I don't know. Var... Vriori... can't say that word. Lots of different reasons for that. I mean, I had an excellent teacher for algebra, and I loved algebra. [Mmmhmm] And then I...
(Time after 49:00)
I: High school, you mean?
S: Right, high school.
I: OK.
S: And then when I took calculus, like, there were just some other things going on in my life that, like, I wasn't focusing on school as much, and I didn't get as good grade in it.
I: Uh huh.
S: And the teacher was different, although he was still a good teacher, I just... it was set up differently so I probably didn't learn it as well which is why I didn't like it as well.
I: Hm.
S: If I had had the same teacher teaching calculus as we did algebra, and during, like, the same time, assuming I know now (?)... then I probably would have liked calculus just as much as algebra.
I: So it's just... it's more related to the people and the circumstances around that time in school?
S: Yeah, I think so.
I: OK. So, just a little preview. We're... next week, if you haven't seen it, it'll be more motion graphs, but it'll concern acceleration, too. And instead of walking, you'll have a cart, so the graphs should be smoother.
S: OK.
(Time 50:00)
I: There will be... there will be opportunities for mistake catching, um... so, next time we talk, which'll probably be Monday after next, no... Monday after Monday after next.
S: OK.
I: Uh, I think...
S: A week from Labor Day?
I: Well, we don't have any tutorial next week.
S: Right.
I: Your tutorial's on Monday.
S: Right. Labor Day.
I: So... the Mon... your next tutorial will be a week after that.
S: Mmmhmm.
I: And so we'll talk about it a week after that.
S: Oh, two weeks from Labor Day, then.
I: Probably.
S: OK.
I: Oh, wait a second, no! That's right. I remember now. We agreed to do it at the end of your lab.
S: OK, we can do that.
I: So I will... I'll have time to check out what you do. And, right. I think that's a good idea, cause it'll be fresh, you won't have to think back so far. You'll actually remember what I'm talking about.
S: OK.
I: Um.

S: Yeah.
I: There'll be more of this mistake checking kind of thing, but that tutorial has another goal in mind, and we'll just see how well that worked.
S: OK.
I: So, um...
(Time 51:00)
S: I mean, I don't think it's a bad thing to learn to catch your mistakes, I just think you should already know how to do that this time in your education. I mean, I'm not saying anything...
I: So I'm not... I don't think this is disagreeing with that.
S: OK.
I: What... what what... this is asking is, uh, what do you see as the main benefit of trying to catch your mistakes?
S: OK.
I: And I think on that, people have different opinions, which we want to hear.
S: OK.
I: It... I mean, was it not useful to you to hear those other opinions? Not so much? Or?
S: I suppose. Slightly useful, they're not going to make a big difference in my life or in my grade in this course, I don't think.
I: Right.
S: But as far as just giving me, uh, you know, 5 seconds of thinking, "Oh, OK." Maybe that's useful for me.
I: Hm. That's interesting. OK. So let me... I think, this is my copy?
S: Yeah, I'll take mine back.
I: I think that's it, so... stop.
end tape

Interview 2: The acceleration tutorial

The epistemological point of this tutorial was for students to discuss the value of studying competing arguments. Many will say that studying incorrect answers is not fruitful; one should just get to the correct stuff. However, we would like the students to be able to analyze multiple points of view and discern the right and wrong parts of each.

(Time 0:00)
I: All right, I think we're good. All right, so that's the tutorial you have. Um... so... we're most... so... like I said, I just finished watching your tape. The detail that I had to go back and rewind, I'll mention as we're talking about it.
S: OK.
I: Um... and that will be most of this, and since I don't have a full survey, uh, thing to go over, that's why this will probably only take half an hour, but we'll see. Um... I guess... the... I mean, before we talk about any specific bits of the tutorial, I wonder if after having seen this, you treat some of these questions on this survey we gave you originally differently than before. I don't know, so... I didn't even bring what you had... what you had done, cause I don't want to sort of bias what you think. Um, but I'm curious about these two questions 19 and 20, where you have... just because they're position/velocity...

(Time just after 1:00)
S: Mmmhmm.
I: ... kind of things. And, I just want to see what you say to them now. And we can even use the frame of the survey I gave you, like, which one, sort of makes the most sense, which one do you think a scientist or a tutorial instructor or something would give. If they're different or the same. Whichever. So... uh...
S: OK, well, for this one, I say their speed is, um... oh, do they EVER have the same speed?
I: Mmmhmm.
S: Yeah, I think it's... well... this one I like.
I: Well, what... I mean, what you said back then is not... that important.
S: Yeah, but I remember this one, and I... OK, so what... it was like... between 3 and 4, I think they were about the same. [Mmmhmm] 2 and... OK, 2 and 5. So I say they have the same speed at... wait... at some time interval between 3 and 4.
(Time 2:00)
I: How did you decide that?
S: Because from looking at it, um, just estimating, it looks like... OK, so, first of all, the top one is moving slowly. Then it speeds up and is moving faster than the bottom one, which remains at constant speed.
I: And how do you tell?
S: Well, this is position over time, right? Yeah, every point two seconds. So every point two seconds, they clocked the position, and this one, you can see... I mean, you can't see perfectly, but they appear to be about the same distance.
I:: OK.
S: So after the point two seconds, it moves the same distance every time. Whereas this one moves just a little bit, but then moves a lot more. So you figure between there, somewhere, it's gonna surpass this one, at the second it surpasses it, it's gonna be... right before it surpasses it, it's gonna be the same. And, uh... looks like it does that between three and four, cause that's when this length is about the same length here. We know this is a length it takes to travel... the time period point two seconds. It goes this length
(Time just after 3:00)
I: Mmmhmm.
S: when it's at the bottom speed. So it's about that length.
I: So... so... you know, asked for a quote-unquote "scientist answer," let's say you only had one crack on a test at this, you would... you would give choice E as your answer?
S: Yeah.
I: And that... and that seems to make the most sense?
S: Yeah.
I: OK. Um... what about... what about this one? This is an acceleration question. So it's the same intervals...
S: Mmmhmm.
I: And... and, I mean, it's a strobe picture just like 19, but the picture looks a little different.
S: Um... yeah, the accelerations, they each... they're each moving at constant speed, although the speeds are different. But they're moving at a constant speed, so that would mean their acceleration's the same. Both zero, actually.
I: Both zero, so that's...
S: Yeah, B.
(Time 4:00)
I: B says they're greater than zero.
S: No wait, oh, here it is. D.
I: OK, so you like that one?
S: Yeah.
I: OK.
S: It may have been different than what I put. I don't remember what I put for that one.
I: It is different.
S: It is different?
I: It is different. But, I mean, does this answer make sense to you, you think?

S: Yeah.
I: I mean, how... how do you make sense of it? Or, I mean...
S: Well, they're not speeding up or slowing down. So the acceleration is zero.
I: OK. Um... right. These are, I think, strangely, the only two ones that explicitly deal with velocity and acceleration along one line, which is kind of what your tutorial was about.
S: Mmmhmm.
I: So... um, yeah. Just... just... just for your information, I think on this question, you gave the same answer the first time, on this one, you gave something else.
S: Yeah, I think I put maybe A, or something.
I: I don't remember, but...
S: I was probably thinking of velocity instead of acceleration when I answered that.
I: Oh, and... 20? You... you said something like B is greater than A?
(Time 5:00)
S: Yeah... yeah, cause the speed... the speed... the velocity of B is greater than A, so... yeah, maybe I put that.
I: Cause B's going faster?
S: Yeah. So I confused velocity and acceleration.
I: OK. On this tutorial, I mean, is that a mistake people could make?
S: Oh yeah.
I: You think? All right, so, um... you still haven't gotten the book yet?
S: No.
I: Where... how'd you get this copy of the tutorial, then?
S: A friend.
I: Oh, copied it? You just Xeroxed it, or something?
S: Is that OK?
I: That's fine, that's perfectly cool. Um... all right, so, I didn't see the nature of the mistake, but at the very beginning, on the first prediction, you had a groupmate, I think it was the one sitting on the same side of the table as you.
S: [Annette].
I: Um, she made a mistake somewhere [mmmhmm] in this, do you remember?
S: Oh, I don't remember what she wrote, but I do remember we were discussing it with... with her. Um, I think she might have had the acceleration and velocity graphs identical. Both with the...
(Time after 6:00)
I: OK.
S: Increase in slope.
I: I mean, I... um... you think you actually talked about that a bit? I didn't write down for how long you interacted about that, but it... I didn't remember it being very much.
S: Not a long time, but I remember we did discuss it, and... like, cause... in doing this for a couple weeks, I notice that, um... [Deena], [Aaron], and I tend to get the same answer, and [Annette] tends to differ more often.
I: She disagrees with you more?
S: Yeah. And, uh... so... as soon as the three of us pointed out, like, why we did it, she was just kind of like, "oh, OK, I guess that makes more sense than mine." So, I mean, we discussed it, but...
I: You think that helps her?
S: Yeah. I mean, I hope it does.
I: Do you think it helps you?
S: Yeah.
I: How is that? I mean, you can't speak for her, but maybe you could speak for yourself.
S: Well, if someone gets it wrong, I have to explain it to them, or someone has to explain it to them. And, you just learn more by teaching it to someone.
(Time just after 7:00)
I: OK, uh, actually, I mean, I noticed that you did... uh, a lot of the talking, especially in explaining it to the TA or someone else in your group. And you're more comfortable with these things now, or... I mean, you're more comfortable with this tutorial than you were with the last one?
S: Well, I liked it better.
I: Why is that?

S: I don't know, the little car, and stuff. That was cute, I guess.
I: OK. Um... so, uh, this was mostly the same thing, the prediction / discuss / [mmmhmm] do it. Was that as useful this time as it was last time?
S: Yeah, I'd say.
I: Doing the predictions? Cause actually, when you did the brake, the brake question is here...
S: Mmmhmm.
I: I mean, you have a drawing down, but I think you actually skipped it.
S: Yeah, I forgot to predict, we actually...
I: So what... so what are the lines on your paper?
S: Well, I just copied what we had, because I... we... we kinda got going fast, and then we actually did the experiment before we did our predictions.
(Time after 8:00)
I: OK. The point is, though, um... I mean, I watched... I watched you do this, you skipped a prediction, but then you did the experiment, and... I don't know if it really looked like that, but when you were talking it over, all of the features of the graph that you were pointing out looked pretty good. I mean, you were pointing out that this had a... this had a velocity that was kind of going down during the... I mean, we only care about the part after you push it, right?
S: Right.
I: Motion after it gets pushed. So you were pointing out this part of the motion here [mmmhmm], and it was going down, and the acceleration was negative for some of that. So those were... those were all of the key features, um... so, I mean... was this part of it helpful to you given that... I mean, I... in the grand scheme of things, I don't really care whether you skip it or not, I just wonder if it was useful anyway without having done that.
S: Was... graphing it useful?
(Time just after 9:00)
I: Well, doing... doing the experiment, just seeing what it is, putting it down?
S: Yeah. I probably... I probably do learn a little bit more when I do a prediction cause it makes you have to think about it more. Um... but it's still useful looking at it... seeing... because, you know, even when you graph it, there's... that... the... whatever program we're using, if you don't stop it right away, it hits the wall, so you get crazy lines. So you even have to, like, know what part of the graph you're looking at, and why.
I: Were you able to figure... I mean, without doing the prediction, were you able to figure out after seeing it what part of the graph was important?
S: Yeah.
I: And... I mean, I know you talked about it afterwards, did that all seem to make sense?
S: Yeah.
I: OK. Um... I guess the next thing... let's see... your group... I don't know if you do this intentionally or not, but when you were going over these four questions, even before the TA showed up, each of you took one.
S: We each took one?
(Time just before 10:00)
I: Yeah, like, [Aaron] took this one, uh, [Annette] took this one, you took this one... right? I mean, when you were talking about it in your group, you just sort of took turns answering one. I just want to see...
S: I just did that out of habit, I guess.
I: yeah, the wording has changed, um... I think, from, you know, the version I was looking at to watch your tutorial, and I want to see what D is, cause that's the one you answered.
S: OK.
I: And, uh... you hinted, and that's what you have written down. See questions A and B. Checking for consistency is the president for life of mistake avoidance strategies and the basis of the development of the scientific viewpoint. Can this be used with velocity and acceleration graphs? So you say, yeah, see questions A and B. So what does that mean?
S: We... ans... the two things you can tell from, you know, comparing them... you look at the slope and that tells you, you know, whether the... uh... acceleration is large or small. And then you look at the, uh... also the slope, and what direction it's in tells you if the acceleration is positive or negative. I just didn't want to write down the whole thing again. I mean, if we were handing this in, I would have

written it out clearly, but this is just for my own knowledge, so...
(Time well after 11:00)
I: Yeah, I mean, you're not turning that in, that's right.
S: Right.
I: Um...
S: Yeah, if we were writing these to hand them in, I'd clean it up, but...
I: So, um... do you remember the stuff the TA tried to say to you at this checkpoint here? Um... you were going over some of the brake stuff, and he was trying to tie it to the first tutorial.
S: Um...
I: Do you remember that at all?
S: Not really.
I: I guess I... I don't have that. He and [Annette], I think it was, were having a long...
S: Oh yeah, they talked for a long time.
I: Yeah, what'd you think of that?
S: Well, um, it was funny cause they were just talking about it, and, like... I mean, yeah, we were kind of just, like, all agreeing and, like, waiting for her to understand it or him to summarize it. But then, I don't know if you noticed... a few minutes afterwards, um... [Annette] was... she was still on the same thing, and then she rephrased her question, and the three of us were just like, "Oh, well you mean this!" And she was like, "Oh, that's all I wanted to know!" And the TA was trying to explain something... I forget what it was. Oh, I think she wanted to know why... or wait, no, maybe I'm talking about a different point. She wanted to know why the accel... she wanted to know why the acceleration was negative when things were still, like, speeding up.
(Time well after 12:00)
I: When things are speeding up, and... but wait... but wait a second. I mean, before the star, where would you have seen that?
S: Hm?
I: Right? That was a big issue for her on this part.
S: That was here? OK. Maybe I'm confusing discussions when I remember.
I: OK. So, maybe... I'm not... I'm not sure what her specific problem was, I guess I could have written that down. Um...
S: Well, he asked her about number C, and she explained that... or... letter C, and she explained that pretty well.
I: But, I mean, she got it right the first time [yeah], so there was something else that was confusing. Um... I mean, do you think... for whatever was confusing her at this... at this point, could you have done the same thing?
(Time after 13:00)
S: Explained it as well as the TA?
I: Yeah, that the TA did?
S: Yeah, I think so.
I: The rest of your group?
S: I wasn't paying... oh, I probably don't remember it cause I wasn't paying attention that much. Um...
I: While... while the two of them were talking?
S: Yeah, cause it seemed to be more one on one, and the three of us were just kind of waiting. But, uh, I mean... I don't have a problem with that, I just was kind of phasing out a little bit.
I: It's easy to do. I guess I don't blame you for that. Um... so, I wanted to see, cause, um... yeah, I can't see your papers on the tape... what this prediction was like for up and down the ramp.
S: Yeah, I was way off. *laughs*
I: OK. But, I mean, but your group agreed on this shape, right?
S: Yeah, we did. I hope so... I have a pretty good way to convince people, even when I'm wrong.
I: Oh you... you actually think that you're the one that convinced them that this shape was right?
(Time just after 14:00)
S: Well, cause I had drawn that [mmmhmm], and, uh, [Aaron] had drawn something which was actually a lot closer to the truth, he had drawn, um, a dotted line right beneath the x-axis.
I: For... wait, for what, velocity?
S: Er... oh, no, I'm confusing with acceleration.
I: Mmmhmm.

S: What did he write for velocity? Well, maybe we all had that.
I: I dunno, but...
S: But we were all pretty sure that was right, until we did the experiment.
I: But then you actually did it...
S: And we realized that, oh, well yeah, this line actually makes a lot more sense.
I: OK. Now... this is partially a fault of the way that this is written. And this is the thing I went back to check, right?
S: OK.
I: So you... you do this prediction, you compare and discuss. And the next thing is discuss... is the acceleration zero at the peak? I'll get back to that with you in a minute.
S: We had a lot of confusion about that.
I: Then acceleration on the way down. Then a reason why a smart student, etc., etc., we'll talk about that, too. Then, experiment. The experiment is down here.
(Time after 15:00)
S: It's not down here?!
I: No.
S: Aaaagh!
I: It never says to do it, but you did it.
S: Well, cause that's the way all the other ones were set up!
I: That's the way all the other ones were set up. Right. Um... so, there was... there was a case where, I think you were confused about this part [mmmhmm], like, doing the two predictions. Do you think that had anything to do with the fact that you... did it once and saw what it was?
S: No, cause we didn't look at the acceleration part. I think we just looked at the velocity part.
I: You on... oh, you only looked at the velocity. I see, so...
S: And we looked, like, we did, all the velocity stuff. [uhhuh] And then looked at the... we did the experiment, like, we predicted...
I: Oh, you did the experiment for velocity, and then everything else you talked out was the acceleration, [yeah] and then you did...
S: So we did it twice, for...
I: OK. So, I guess, then, my only followup is, I mean, you kind of saw what the velocity was then?
S: Mmmhmm.
(Time 16:00)
I: I mean, you know how to get acceleration from a velocity graph.
S: Yeah, I know.
I: So, I mean, was that kind of a giveaway that affected how the rest of this page went?
S: Um, a little.
I: I mean... I mean, could you have gotten more out of the acceleration questions had you not done the velocity thing first?
S: Maybe, I don't know.
I: OK, um...
S: We still had a lengthy discussion about it, so I think...
I: I noticed that, so that's fine. I mean, you know, I'm not trying to... I'm not trying to criticize the way you did the tutorial, like I said, you have a very good reason for doing the experiment...
S: Well I just... they were all set up that same way.
I: Yeah, um...
S: Then question, so...
I: Right, um... [Aaron] made a comment when making the predictions here about, uh, throwing a ball up and it dropping.
S: Mmmhmm.
I: You remember that?
S: Yeah, he was talking about the force of gravity being constant.
I: Did that help you think about this situation at all?
S: It did.
I: Does it... I mean, does it apply?
(Time just after 17:00)
S: Well, um...

I: (You don't?) sound that sure.
S: I... this was the graph where I was convinced I had it right and I actually had it wrong was my dotted line, you can see here. Um... it makes this bend. [mmmhmm] And his was close... his was actually, yeah. He drew this line.
I: So he drew that...
S: straight line.
I: And you talked those over before doing the experiment, right?
S: Right, we talked 'em over.
I: So which were you more convinced of?
S: I was more convinced of mine, actually... until, I guess, when we got closer to doing it and pointed out that yeah, it would remain constant, cause, like... I think we did look at the velocity graph, and noticed that yeah, that slope is constant, therefore this has to be constant. But the thing that really threw us was when it hit the peak, what to do about that, so...
I: OK, so... uh, I guess that's... that's the next series of questions I have for you. Cause you... you said a couple things here but I'm not entirely clear on... on elaborations and such. Um, you think acceleration at the peak is zero?
(Time after 18:00)
S: Mmmhmm.
I: OK. Is that different than what this graph says?
S: Yes. But, perhaps not.
I: Why... why not, possibly?
S: Cause we don't know how sensitive that, um... that scanner is?
I: Mmmhmm.
S: And it's only at zero for a fraction of a second, so maybe it's not... noticing it every little bit, and for that tiny instant, there would actually be a leap in the graph, or something. So we're not... we're not 100% sure of that, and [Aaron] and I left the situation still without...
I: Still a little unsure?
S: Yeah.
I: Um, if I ever talk to him, I'll have to ask him. Um... so, do you... so, this is a conflict. Do you think there's a way to reconcile it, or no?
S: I don't know.
I: Right now?
S: I can, uh, do some... do some other equations and see how it turns out.
(Time just after 19:00)
I: What equations do you mean?
S: Well, do some calculus and see exactly what happens at zero for derivatives.
(pause)
I: So, hm... all right. Um...
S: Graph some things on my calculator, because I... I'm more familiar with that, and, um... see how those graphs look.
I: I mean, is it possible on a calculator to graph a line like that, and check... check what the derivative is at each point? I don't know what [yeah] calculators nowadays are capable of.
S: Yeah, you can do that with most graphing calculators.
I: OK, um... I think you had some... I mean, you found something strange about these questions... uh...
S: We just thought it was comical that it would specify a smart student.
I: Why?
S: Why?
I: Yeah.
S: Well, what difference does it make? I mean, they're... a smart student, why not just "a student" or anybody? Just say, "a reason why someone might think it's this way. A reason why someone might think it's this way." We just thought it was comical that they're like, "a SMART student."
(Time after 20:00)
I: Well, right, um... I don't know what to say about that, uh...
S: I guess they just wanted to emphasize that this is a person who's actually thought about it and not just having no clue on what's going on, maybe.
I: I mean, so I... I guess it's good that I let you speak there. So, I... I mean, that sounds... sounds

reasonable. If people assume that it's just someone with absolutely no clue, then they can... then they can come up with something that, you know, won't give this question any... any purpose, really. Um...
S: You could even say "give a reason why YOU might think it's this way." I don't know, it's just the phrase "smart student" struck us as funny.
I: Right. Um... the problem is... uh, the problem is a lot of people... uh, I mean, once they get the hang of it and, you know, see the velocity, they'll get the... they'll make the right prediction. And people find it hard sometimes to think of an answer that's wrong.
(Time 21:00)
S: Oh, OK.
I: Right? Um... I mean, if you had gotten this right, I mean, does it make a lot of sense for us to ask you, "think of a reason for a wrong answer?"
S: If I had gotten it right, what's the reason...? I don't know.
I: Is that worth your time?
S: Maybe. It kinda depends on what you're doing, I don't... I'm not really sure.
I: I mean, we coulda... we could have done this last time. I mean, do you remember the last tutorial, uh... a lot of your predictions were right.
S: Mmmhmm.
I: Um... like, like picture walking away slowly. Your position graph is just a diagonal line up. Um... we might ask a question like, "give a reason that a smart student would say that the velocity graph... goes up also, and looks like that."
S: OK.
I: Is that a question that's helpful for you for us to ask?
S: Well, I suppose it is a little helpful, because it...
(Time 22:00)
I: It's an easy question that you got right, but...
S: Yeah. It's... it's, uh... helpful in the same way that working with someone, and they get it wrong, that you... explain why your answer is right. I mean, it's... yeah, I'd say it's a little helpful.
I: I mean, it's... it's kind of a different kind of task than the one you described, though, because that's... that's, you know, someone coming in with an honest wrong answer.
S: Mmmhmm.
I: I mean, questions like this, now you have to come up with one, for some reason.
S: Yeah, but if... if you're familiar with the subject and you've seen what people put as answers, you can just think of... you know, or when you were first learning the subject, think of mistakes you made and just remember it.
I: Mmmhmm.
S: I mean, I don't think coming up... in this example, at least, I don't think coming up with a wrong answer was particularly difficult.
I: OK. This is about where you ended, right?
S: Yeah, we ran out of time.
I: Yeah, I think so. Um...
(Time just after 23:00)
S: Cause we had that lengthy discussion.
I: Oh, that's perfectly fine. Um... some of these are... some of these are... (pause) repeats of some of the consistency questions. One of the ones at the end asks, "can you use consistency, I mean, knowing what velocity is, to decide if acceleration is, um... zero at the peak or not?" OK, so... I mean, just from this graph, what... what would the acceleration at the peak be?
S: Well, it'd be the same as the other places.
I: So would it be positive, negative, or zero?
S: It'd be negative.
I: OK. But you had a concern before that the detector might not be sensitive enough to catch it.
S: Well, I don't know, it just... I suppose back on that survey between intuition and science that I would differ on that question, then. Because it just... it seems like if your velocity is zero, your acceleration has to be zero.
(Time after 24:00)
I: Um, that's the answer that makes sense to you?
S: Right.

I: That's not explicitly a question on here, but...
S: Right.
I: Uh, so, why does that make sense? That it... that the acceleration is zero, or, sorry... if velocity is zero, acceleration is zero?
S: Well... because... they're both a measure of change in position, and if the position's not changing, then how can you measure the change in position?
(pause)
I: OK, I was just trying to parse what you said, but I think I got it. Um, all right, so we're about... about done, I think. Just one of... just want a reaction to one of the questions that you didn't quite get to. Um... so, what's the next move here? Um... Venus and Serena, I don't know where we got those names...
(Time just after 25:00)
S: Oh, they're the... tennis players.
I: Yeah, *laughs*, right. Um... we get names from everywhere. We were asking for prediction graph 1 and 2 before. Um, the part... we weren't asking specifically the issue of the acceleration at the peak, we were asking about the acceleration as it was speeding back down the ramp.
S: Mmmhmm.
I: The things you were asked to, to... to distinguish between are: um, is it positive, or is it negative? Right? And you, actually, were the one that were giving the strongest arguments for why it should be negative both times, right?
S: Mmmhmm.
I: OK. So, the two statements they're making... one of 'em says, you know, we know which one to believe... once you do the experiment, um... we know what it is. We know that the acceleration's negative. Um... uh, but there are arguments that the acceleration is positive. Did anyone in your group think the acceleration could be positive coming back down the ramp?
(Time after 26:00)
S: I think, uh... maybe [Annette] might have said something about it, but then when we talked about it, she saw more reason for it to be negative.
I: OK. Um... so, I mean, I guess looking at these two statements, which do you agree with?
phone rings
I: I'm gonna ignore that.
S: Yeah.
phone rings
S: Well, I'd say I agree with Serena more.
I: Um... OK.
phone rings
I: How's that?
S: Well, if... there's someone in your group who's still not understanding it, you need to... I mean, even if you know that this is what happens, but if you're not understanding the concept, I mean, that's the point of the class, to understand why.
I: Mmmhmm.
S: So it... there's... you know, something that's blocking you from understanding why even if you know what
(Time just after 27:00)
I: Well, I mean, but... I mean, but, the three of you, or maybe just the two of you, whichever ones of you got it right... I mean, I've seen groups before where everyone was just sort of on the same page and got it.
S: Uh huh.
I: Um... I mean, would that be enough for a group like that if there wasn't sort of a dissenting voice in there saying, "but, you know, I think it's positive."
S: Well, it depends.
I: Mmmhmm?
S: Um... if everyone really gets it and they're very familiar with it, then sure, it's fine. But if you're coming at it to the first... if you're coming at it to the first time, and everyone just guesses the right answer, then I'd say that's not as good. And it's... good to have someone with the wrong answer so you have to actually think about why your answer is right. But, you know, if... if we were doing this

tutorial at the end of the year, or even next week, and we all got the same answer, then that would be fine, cause we already know it.
(Time just after 28:00)
I: Cause you've seen it once.
S: Right.
I: Talked it over. OK. Um... yeah. So, I've gone through all of this. Just make sure... I asked all of that... asked all... didn't mean to take your stuff...
end tape

Interview 3: The Newton’s Third Law tutorial

This is one of the more important tutorials since it is examined heavily in Chapter 5. The epistemological point of the tutorial is that an intuitively difficult concept can be reconciled with common sense. Patty’s response to this tutorial inspired a lot of the ways we looked at her data.

(Time 0:00)
I: Do you have, do you have your... thing there? Your tutorial? I don't... there's not as much graphing in this one, so it might not be as important, but I'll look at what you wrote specifically, but...
(pause)
I: OK. All right. So, yep... this is the N3 tutorial, of course.
S: It was number 3, not 4. (referring to the wrong number on my copy)
I: I'm... this is the same thing.
S: Oh, OK.
I: This is just an old... we have... we had a different numbering system on the copy I printed out, so don't sweat it.
S: OK.
I: It's the same content. Um... so, uh... am I... am I remembering right? I think your whole group agreed on this at the beginning. Um... the intuition was that the force was greater from the truck, right? The truck exerts more. Um, did you expect that to be right when we did the experiment? When you were shown the demo?
(Time just after 1:00)
S: Um, I think I probably expected em to be equal.
I: Why is that?
S: Cause that's what the law says.
I: That's... so you thought the experiment would agree with the law [yeah] somehow. OK. Um... OK. Then you actually did it, and the experiment worked well?
S: Mmmhmm.
I: And you saw it was the same? OK. Um... Dianne and [Annette], I think, they were responding to this part... this question in part 2. And they both said choice 2 was the one that was their favorite.
S: Yep.
I: Or something like that. Um... you and [Aaron] both said you were kind of torn between one and two. Now, he sort of made a comment about why one was appealing, but you didn't say too much about it. Um, [well, I...] do you know why you were torn between choices one and two on...?
S: The same reason as him. Like, I like the first part of one, we shouldn't dwell on these things, and stuff.
(Time just after 2:00)
I: OK, uh, and... why do you agree with that? What about that part of choice one is appealing?
S: Well, you're not gonna really learn anything by just sitting there dwelling on it, and, like, worrying

about it, I mean... I don't know. So, like, that part of choice 2 saying there's probably some way to do it, but right now I don't know. And part of choice 1 saying I shouldn't dwell on it, and we should focus on learning. I like that, too.
I: Learning when it does and doesn't apply. OK. Um... all right. So, *sigh*, OK, you gave an idea on this part 3, uh, that... we said the truck slows down by 5 meters per second and to apply the intuition that the car reacts more.
S: Mmmhmm.
I: Was I seeing it correctly that, uh... that you... you were kind of using that when you guessed 5, I mean... 5 was kind of the answer you liked at first, right?
(Time just after 3:00)
S: Yeah.
I: OK, so... can you articulate for me... [well] how... I mean, you said... I know you said something about it on the tape, and I have it down, but I just wanted to see what you said... what you say now... how the 5 relates to a "car reacts more" kind of idea.
S: Well, I was just trying to come up with something how intuition would not interfere with what the law stated, and the law said that things must be equal.
I: Uh huh.
S: And we didn't know at this point whether we were talking about force or acceleration, we hadn't gotten to that part yet.
I: Right.
S: So the law says it's equal, and intuition says it's different, so... [mmmhmm] going by the law, it's gonna have to be 5. But, like, if you just think about it, like... when something is speeding up, you tend to think, like, more force, more power needs to go into something that's speeding up than slowing down.
(Time after 4:00)
I: Can you think of a specific physical instance where it's harder to speed something up than it is to slow something down by the same amount?
S: Well, um, if you're pushing something, it's a lot of force to, you know, push it, but if you need to slow something down, like, there's other forces involved there which help you, so it's not as hard to slow something down as it is to speed it up.
I: What might help you?
S: Friction, gravity...
I: Oh, OK, so... so that makes sense. Um... so, I... I mean, I understand... I mean, it was clear through watching it that you got the point of this. I mean, your whole group pretty much got the point of this and worked a lot of it out. Um... but I also see how at the time, the 5 meters per second you were trying to make... make that agree, I could see how having the changes in speeds be the same
(Time after 5:00)
S: mmmhmm
I: might be the kind of agreement that you might expect a law to come up with. Um...
S: Wait, I wasn't, like, steadfast as... this is the way it has to be, but I just threw out another idea of how it could possibly work.
I: About, about... about the five, right? Defending the five. Uh, at the time, [Aaron] gave a reason why it should be ten. Why the car should pick up ten meters per second. Um, was... was your explanation of 5 at the time as convincing to you as his for 10?
S: Well, I didn't understand exactly what he was saying at the time.
I: Mmmhmm.
S: Um, but we ended up doing what he said, so...
I: You mean you used the... the actual 10 in doing all the math?
S: Yeah.
I: Right. Um... so, so his argument for why it should be 10 was, you know, that the car reacts more, so its change in speed should be greater. And the factor should be two because that's how much bigger the truck is, the truck's twice as big.
(Time after 6:00)
S: Mmmhmm.
I: So that's 10. Um... I mean, at the time, could that... could that sort of intuitive guess been as appealing to you as the five that you had come up with on your own?

S: Yeah.
I: OK. So that's... that's an interesting question, so... those are two different ideas that, um, (pause) make sense to your intuition. Each in different ways. Um, when that happens, how would you decide between 'em?
S: Well, think about the one that makes more sense, or...
I: How do you decide which one makes more sense?
S: I don't know. I'd have to think about how each idea was came up with. A lot of it probably depends on how the idea is explained. Um... it depends on how familiar I am with the topic. I wasn't too familiar with this.
(Time after 7:00)
I: OK.
S: So... maybe that's part of the reason that they both agreed with me is I wasn't too familiar with it. (pause)
I: OK, um... right. So, um, moving on from that issue, you were actually trying to calculate the accelerations, um, and you were asking some kind of question about... about how to do it, right, what's the formula for it?
S: Mmmhmm.
I: a is delta v over delta t. Does that seem to you more like sort of a mathematical equation that you use to get the quantity, or is it something more like a definition? Or is there... or is there a difference?
S: It's both. A mathematical equation is a definition. Well, in a way. I mean, you... mathematics is a language. [uh huh] English is a language, you can use either one to define things in science. And if you know what the variables mean, then the mathematical definition is just as good as a word one, so...
(Time after 8:00)
I: OK, um... also, some people in your group were reasoning using the a=F/m, or maybe it was a different question somewhere along this path.
S: Yeah, that was a different question.
I: Uh, is that... is that the same kind of formula to you, or different than... than acceleration is change in velocity over change in time?
S: Well, it's the same kind of formula as in its usefulness, but I suppose it's not as good as a definition formula.
I: Why is it not a definition?
S: Well, I don't know, it depends on where you're coming from. I usually think of veloc... or, acceleration in terms of velocity and time... just when I see the word acceleration, I think of movement and velocity and stuff like that. And I don't think of force right away. And... I mean, I suppose you can come up with just as good definition of acceleration using the terms force and mass, but I think it's usually defined with velocity and time. Not that one's wrong, just that one's more common.
(Time well after 9:00)
I: Um... all right. So, I... I mean, what I found was, you know, while you were doing this, and of course, you got this impression, too... once you started doing all the math, all of the mathematical steps were right. And you seem to be pretty comfortable doing it smoothly. So... um, it's... you started out with an intuition that's the 10 meters per second that wound up being right.
S: Mmmhmm.
I: Um... what... I mean, we could have just done that. What do you think the point was, or do you think there was a point in... in talking about it at the very beginning where you had to say something that was wrong? Right? That... that it seems the forces weren't equal.
(Time after 10:00)
S: Well, um, kind of tricky, because they don't really tell you exactly what... I mean, just... what's greater, or which force is greater. And without knowing exactly what force is, cause we're pretty well just started, we just thought up acceleration and thought that was the force, so...
I: Oh, so... so for you, part of the confusion was not really understanding what force was.
S: Well, I guess so.
I: OK, so was... was the point of this to... to clarify that concept, or something else?
S: The point of the beginning, you mean?
I: Yeah, the first section, making you... I mean, not forcing you, but giving you a question that, you know, we know a lot of people screw up.
S: Well, it makes you aware of what you commonly think of as force was actually acceleration.

(Time just after 11:00)
(pause)
I: Mmmhmm. All right. Um... let me see. So... what kind of things did you do at the very end? Uh... (pause) so, the very last part, part 4, I don't remember hearing a lot on the tape about what your group came up with, but perhaps you came up with something. Um... yeah, we have plenty of time, so... I mean, can you summarize what... what was up with this car reacts more intuition as far as is it right, is it wrong? What was your consensus on that?
S: Well, it was pretty much that, yeah, it is right. The car reacts more.
I: Mmmhmm.
S: The thing you have to remember is, what is your definition of "reaction." If your definition of reaction is "accelerates more," then it's perfectly right. If your definition of reaction is, you know, "is affected by more force," then it's wrong.
(Time after 12:00)
I: So it's just a question of putting the right physics term to the word "reaction?"
S: Yes.
I: OK. Um... well, OK, so the next question, what was the... common sense explanation for why the car should react more given that they feel equal forces?
S: Uh, the car has less mass.
I: And that's enough to explain it?
(pause)
S: I suppose. What else do you want?
I: OK, I mean, nothing. If there's nothing else, than I want nothing else.
S: I mean, that's the... major difference. OK, and I guess the, uh, the truck was moving. I could have written that, too.
I: So did... did your group come up with anything for question C about, um, you know, what... what strategies you could use to deal with counterintuitive things? I mean, I noticed your TA said at the very beginning this is one of the most counterintuitive laws in all of physics, right? Something like that.
(Time after 13:00)
S: Yeah, he did.
I: So you're gonna... you're gonna be forced to deal with stuff like this all the time, so... what can you do to deal with it?
S: Well, if it doesn't seem to be making sense intuitively, we can think about exactly what our intuitions are talking about... if we are actually thinking of the same terminology as we are experimenting with, and make sure our mathematics are right.
I: OK, actually, now that I think about it, you did say something like that on the tape.
S: I did?
I: Uh, something like that. It was just a question of, you know, pinning your intuition to something specific and making sure that that's right. OK. So, (there's that?). That's all the specific ones I have there.
(Time just before 14:00)
I wanted to go back to... I mean, just to check, some of the ones... the questions on this initial survey we went through. Again, I didn't... I didn't bring along the, uh... the one you did originally, and, you know, I don't really care what you said then, but... I just want to see if through... through this, how you applied the... the idea you got, um... or the ideas you learned about to questions like these. So, cause we... we gave you a very specific situation where a car... a truck loses a specific amount of speed and a car gains a specific amount of speed. So let's see what... let's see if it has anything to say about that stuff.
S: OK.
I: So, a truck colliding head-on with a car... (pause) I think I asked you about this the first... the first time I talked to you.
S: Yeah, probably.
I: So, which of those makes the most sense now?
S: Well, it's E. They do an equal and opposite force.
(Time just after 15:00)
I: OK. And, I mean...

S: If you're defining force in terms of what we used in the last tutorial.
I: H... how does that work? I mean, with... how do the forces end up being the same in this particular collision? I mean, the car clearly gets smashed.
S: Oh, it gets smashed?
I: Yeah, I mean, the small compact car... it's a head-on collision, so [oh], what happens when the car and the truck collide?
S: Oh, so they're both moving?
I: Yeah.
S: Hm. Well, I don't know, we didn't talk... I was actually thinking at one point, I was gonna ask the TA of that, and then I forgot [uh huh] what happens if the car just gets obliterated by the truck instead of is accelerating. But, um... probably still be E.
I: Um, OK. (pause) So, so the car clearly gets more damaged in the collision.
S: Mmmhmm.
(Time 16:00)
I: So...
S: I suppose force can connect...
I: How is it that it makes sense to you that the forces are the same for this case?
S: Well, I suppose the force can manifest itself in things besides acceleration, which is... what we dealt with specifically was acceleration, but I'm sure there's other things it could. it could come out as. Be observed as.
I: Like what?
S: Well, heat, probably.
I: Or the car getting crunched.
S: Or the car getting crunched, if you can measure it... the degree of car crunching.
I: Car crunching degree, very nice. Actu... that... that isn't so farfetched, actually. There... there is something to that, but... about the acceleration thing, anyway, I mean, what's going on acceleration-wise in this collision?
S: In this collision?
I: Mmmhmm.
S: Um, I guess they're both stopping. They're both... or... the large truck... well, they really don't give us that much information here. But, just picturing it, the car probably gets smashed; ground to a pulp. The car... the truck would slow down a little bit, but then just continue on. If it was a large enough truck.
(Time after 17:00)
I: So... so let's say they all, collided in a crumpled mess. Would it still be moving after the collision in one direction or the other, or not?
S: Uh, it could possibly be moving with a large truck... in the same direction. It would slow down due to some friction when it hit the car and the pieces are grinding up underneath the wheels, and...
I: Mmmhmm.
S: you know, wreckage everywhere. It would slow down through that, but then it would just... continue on. Once it got past it.
(page flips)
I: OK, uh... (pause) so. Yeah, this... this question 15 is one... is one I find interesting, cause it's kind of... it's unlike any other one you've done. So this truck is broken down, and the car is pushing it.
S: Yeah, that's realistic.
(Time just after 18:00)
I: Oh. Well, I mean, if you... if you... why, just cause the truck is so big, and it would be hard to push?
S: Yeah.
I: Yeah.
S: More likely, the wheels of the car would spin, and nothing would be moving.
I: Mmm. Um... (pause) so... right. We claim that the car is pushing the truck and the whole mess is speeding up.
S: Mmmhmm.
I: All right, so... which of these answers here makes the most sense to you?
(pause)
I: Slightly different situation.

S: Um... based on the last tutorial, I'd say A.
I: Uh, what... that A is the correct answer?
S: Yes.
I: Does that make sense in this... in this case?
S: Sure.
I: How?
S: Well, they're touching, so there'll be force, and it's gonna have to be equal and opposite.
I: OK. So... I mean, it... it sounds that you... that you've accepted that Newton 3 holds in this situation.
(Time after 19:00)
S: Yes, I have been.
I: Uh huh.
S: Accepted that.
I: OK, um... one could easily give an intuition that, you know, everything is accelerating, right? And the car is the thing that's doing the accelerating.
S: Mmmhmm.
I: I mean, we're speeding up. So if... if... if the car pushes on the truck less than the truck pushes back, then there's no way it can keep accelerating.
S: It's... can you say that again?
I: So the car's doing all the work here.
S: Mmmhmm.
I: The car's doing all the pushing. So if the... if the truck resists the car as much as the car pushes the truck, then how can it accelerate?
S: Well, you just used the term "resist" and...
I: Exerts. Oh. Good catch.
S: And that's the same thing as the type of force we're dealing with, I don't think so. I mean, it's... it's still touching the car, so it's gotta be exerting some kind of force.
(Time after 20:00)
I: The truck is exerting some kind of force?
S: Mmmhmm.
I: Right, um... but, but I'm saying I might have the intuition that [OK] that force can't be equal, cause if they are, how can I speed up if the truck pushes on me as hard as I push on it? Me being in the car, of course.
S: Right.
I: Mmmhmm.
S: Well, that's right, and I think that's what I put when I first read it, but if... I mean, taking the wall into account, it has to, because they're touching. And the... when you say that you wouldn't be moving if you are exerting equal force, you're talking about something other than the force which Newton's law is talking about.
I: Mmm. OK, so you think that's the way that... that you'd end up making sense of this in the end?
S: Yes.
(Time just before 21:00)
I: OK, I think I follow what you... follow what you mean. Um... so, just so you know, I mean, you'll never see this question exactly on tutorial, but one of the issues that we just talked about will be, uh... in two weeks from now, part of that. Like, how can two things push on each other and the whole thing move? So...
S: OK.
I: that'll be later. So, uh... I didn't ask the other truck question cause it wasn't as cool. Um... 28 here, you remember, you have the big student and the small student on the rolly chairs?
S: Mmmhmm.
I: So A pushes out with his feet on B, and both chairs move.
S: Right.
I: OK, so what... which of the answers there?
(pause)
S: It'd have to be E.
I: It would have to be E, how do you make sense of it for this... for this situation being different than the other situations?

S: Cause they're moving in opposite directions instead of the same direction? I don't see why that matters yet.
(Time just after 22:00)
I: OK, so they're moving in opposite directions?
S: Mmmhmm.
I: So, what about that tells you that the forces are the same, or helps you make sense that the forces are the same on the two people?
S: Well, they're the same cause they're touching, and... I... I don't know, I hadn't considered direction in affecting the force that much. I mean, if they're pushing away or... going in the same direction they're pushing, they're still exerting force on each other.
(pause)
I: OK, so... I believe... I understand that, you know... you know they're exerting forces on each other.
S: Mmmhmm.
I: The question is... what about the situation helps you make sense of the answer you gave me which said that the forces are the same size? I mean, how can I look at this and sort of intuitively think, "OK, those... those forces are about the same"?
(Time after 23:00)
S: Well, well I don't know. But, uh... if they're about or exactly, that... according to Newton's Law they have to be exactly, cause that's just the way the world works. And...
I: OK, so if... so... what would you say to me if I was someone in your group, right... and I said, you know, A is the one doing the pushing. You know, A pushes on B, and we see B flying off to the right.
S: Mmmhmm.
I: So... how can they be the same?
S: Well, you're talking about something different than the force that Newton was referring to.
I: Which force... was he referring to?
(Time before 24:00)
S: I don't know... we need another term for force, because... yes. Student B is not doing anything, he's not exerting himself physically in any way, he's just sitting there. And B... or A is doing work, he's... um, you know, his muscles are moving, and he has to pump the blood, and all that, so he's actually doing something. And that something he's doing... um, can be called force, but it's a different force than the type of force where... two objects are touching, so they have to be exerting the same force.
(pause)
I: Oh, so... hm... so this isn't the case like the car and truck collisions, so...
S: Sure it is!
I: Oh, wait, it is. I forgot what you were responding to exactly. Um...
S: I mean, I haven't seen anything to tell me that this is going to be any different from any of the examples we've done where the forces are always going to be equal and opposite when things are touching.
I: There's something about the term "force" you don't like?
S: Yes. It's too broad.
(pause)
(Time 25:00)
I: Um... what are the various things it could mean?
S: Um... it could mean acceleration...
I: You're sort of implying that it's ambiguous, right?
S: Well, yes.
I: Mmmhmm.
S: We... when we did the... tutorial, we thought of force in terms of acceleration. And it was actually different things, but we called both of them force when actually one of them was deemed force, and the other one was called acceleration. So I'm saying in this case there could easily be another thing similar to acceleration, but also different from force.
I: Oh, that... um...
S: We just think it's force intuitively when it's actually something else scientifically.
I: So... scientifically you've accepted that the forces are the same.
S: OK...
I: No, I mean, have you?

S: Yes.
I: Oh. I'm... I'm not trying to put words in your mouth. That was supposed to have sort of a question mark at the end, but I guess I didn't [that's ok] inflect it. Um... I mean, in this physical situation, what do you think the accelerations of A and B are gonna be like?
(Time after 26:00)
S: Um... when they actually push em?
I: When they push off, yeah.
S: Um... I think B will go farther.
I: Uh...
S: Faster, further.
I: Is that acceleration?
S: Well, yeah, I guess it could be.
I: So... will B have more acceleration?
S: Yes.
I: Will A have any at all?
S: Well, yeah, it'll have to. Although he'll be, like... making the acceleration by himself.
I: OK.
S: Cause he's the one who's gonna be bending his knees and pushing off.
I: Oh, so you... you think he'll be moving off to the left just cause that's what naturally happens when he straightens his legs out. Is that right?
S: Well, I think he'll be moving a little bit further than that.
I: Oh.
S: Just from, like, the... I don't know... the way things on wheels and the action of pushing someone away would probably send you back further than the action of just straightening your legs. I mean, he's not... is he just straightening his legs out? Oh, it says suddenly.
(Time after 27:00)
I: Suddenly pushes out, so it's like *djjt*.
S: Yeah, so he's gonna...
I: Let's demonstrate right now. No. Don't have the space.
S: That would hurt, I'm not on wheels.
I: Oh, you're not?
laughing
I: I don't want to hurt... I don't want to hurt people that are doing me favors. So... OK. Have you... have you said everything about this you wanted to?
S: I think so. If he just straightens his legs out, I don't think he'd go as far as he will if he pushes outward.
I: So he will move to the left a little bit? OK. Uh, I think that's all I wanted to ask about that.
(end tape)

Interview 4: Newton's Second Law

This is another place where conceptual reconciliation was necessary. Many students believe that to pull someone up at constant speed, you need a force bigger than that person's weight. That is true for the initiation phase of the motion only. The tutorial is not just about teaching how to use Newton's Second Law but how to figure out which parts of one's reasoning are right and wrong.

(Time 0:00)

I: Do you have your, uh... do you have your tutorial book again?
S: I forgot to bring my book, but I...
I: You have the printout?
S: No, I just copied the... sheet of paper.
(pause)
I: Um...
S: What did I do with it?
I: Well, if you don't have it, that's OK, I have a copy of all the questions.
S: Yeah, I figured you would. But I have my answers written down. Here they are.
I: Oh, those are the answers?
S: Yeah.
I: OK. Um...
S: Copy into my book later.
(pause)
I: All right. How many pages is this? Only 4?
S: Yes.
I: OK. Sorry that the numbering isn't the same, it's tutorial 4 for you. But it's the one with Timmy's falling down the well, right?
S: Mmmhmm.
(Time just before 1:00)
I: And that's what we're talking about specifically. All right. One of the first things... I noticed was, um, there was, uh... a discussion at the beginning of comparing all the forces, the rope upward exerting a greater, less than, or equal to than 250 Newtons. Um... you had made some kind of statement that it was the machine exerting the force, and not the rope.
S: Yeah.
I: OK. Um... is that... is that still a problem? I mean... I mean, you were clearly thinking of the situation in a way different from the way the question was being asked to you.
S: Mmmhmm.
I: So was that a problem? How was that a problem?
S: I don't know, I just... the rope's not doing anything, the machine's the one exerting the force. It... I guess it really doesn't make that much of a difference.
I: Why doesn't it make a difference?
S: Well, just kind of... they were gonna be doing the same thing, and they're basically part of the same thing, so it really doesn't matter what word you use for it, whether you use rope or machine.
(Time just after 2:00)
I: For the thing that's exerting the force up?
S: Yeah.
I: OK. So, I mean, do you think you could... I mean, clearly you did, but, I mean, would it not affect the rest of the tutorial, then? If I replaced the word "rope" in here with the word "machine" every time it came up, I mean, would that... that not affect your answers or the way you thought about it?
S: No, not after the first question where I was just kind of like, "oh, they're the same thing."
I: Not after what first question? What about this told you that the two were the same thing?
S: Um... I guess answers of my... the other people at the table.
I: Um... OK. So, when the TA came by for the first checkout, he was talking to you as though, you know, clearly it was this rope thing, right? There's this... there's a rope, and there's gravity, and... he was talking as if, you know, your group had already decided.
S: Mmmhmm.
(pause)
(Time 3:00)
I: Um... by then, that question wasn't hard for you to answer, though, cause you had already made the change by then, or not?
S: Yeah, I did, or... I had already made the change by then.
I: OK, so, the fact that the TA comes in talking about ropes doesn't make a whole lot of difference.
S: No.
I: Um... Let's see. So, one thing I noticed... hm... I guess... I guess, just, the first thing... just to be sure, I'm pretty sure you... your group, everyone in your group, you know, did get the point of the

physics of all of this, but, I mean, how does it work out? Your Newton... the Newton's second law answer, what does it say about the upward force, uh, during the part where it's... uh, where it's going up at constant speed?
S: Well, it said it... that they would have to be the same force.
I: OK. Um... you got that answer very quickly at the beginning. Did that contradict an intuition you had, or did it not?
(Time just after 4:00)
S: Well, it kinda does. Because, you figure, same force, it will not gonna be moving at all. But then... [Aaron] mentioned something which was actually what the whole second page was about, that, you know, once you start it moving, then it's fine.
I: Then it's fine. OK. So, that... that's what I was going to ask about next. He, at the very beginning, said that, you know, the kicker in this is that we have not yet asked you to consider the beginning of the motion where it goes from rest to whatever constant speed.
S: Right.
I: Um... I'm... I'm just wondering, since it wasn't immediately obvious for a couple of reasons, I was wondering when... when exactly that sunk in. Um... I mean, did you believe it as soon as he said it?
S: Yeah.
I: OK.
S: I just hadn't thought about it before, but as soon as he said it, it made sense, so I accepted it.
(Time just after 5:00)
I: It made sense. Um... OK, cause after it, there was a comment you made, something like that if the force is greater than the weight, then it would go... that Timmy would go up at a constant speed, but it would be a faster constant speed. Do you remember saying [mmmhmm] anything like that? OK, I think that was after [Aaron]'s comment.
S: Yeah.
I: OK.
S: That was when we were doing the question on the second page.
I: Doing the question on the second page.
S: Mmmhmm.
I: And that was about... uh, oh, intuitively, if the rope's force remains larger than the child's weight, will it keep speeding up, slow down, or rise with constant speed?
S: Mmmhmm.
I: Oh, OK, so your answer that, that you know, if the force is greater, it will go at a constant speed, but just a faster one, was a response to this?
S: Yes.
I: OK. But, does... did that agree with N2, then?
S: Agree with what?
I: Newton 2?
S: Um... (pause) yeah... I don't know.
(pause)
(Time just after 6:00)
S: Newton 2 is saying that the force equals the mass times acceleration.
I: Mmmhmm. Which force do you mean?
S: Whatever one they're talking about in this problem?
I: There are a couple forces in this problem. I mean, Newton 2 says that, you know, F equals ma, but what is the F if there are a bunch of F's? Is it the up one, is it the down one, something else?
S: Each of em. Every one of em. Just... the other parts would be different. You'd have F sub 1, m sub 1, a sub 1, then F sub 2, m sub 2, a sub 2. You're saying you can't apply this same equation for different forces?
I: So, wait, I'm... I'm just wondering how that would work for Timmy. If, I mean, you know, he weighs 250 Newtons.
S: Mmmhmm.
I: And let's say the... the rope's force remains larger than the child's weight, so let's say it's 300 or something.
(Time just after 7:00)
S: Mmmhmm.

I: How would you use... with those forces, how would you use Newton's second law?
S: Oh, you're saying there's two forces on the same thing?
I: Well, there... there are two forces in this problem, I'm just wondering, if you're... if you're applying F equals ma, how do you do it?
S: Um... (pause) I don't know, maybe it would have to be the differences in the forces.
I: What do you mean the difference?
S: Well, the force of the rope minus the force of Timmy.
I: Oh, OK, so... so some combination of the two. All right. I think I understand a little better now that comment you were making about the, uh... about the constant speed but... so, that's right, what you said. That's what we mean by net force, and so Newton 2 is completely F... F net equals ma.
(Time 8:00)
S: Yeah.
I: So, the net force would be 50 up, and that... what would that produce, then?
S: That would produce a positive acceleration.
I: OK, and so is that consistent with... a high constant speed?
S: No.
I: OK.
S: I was... I was talking about constant speed which would be, uh, an acceleration of zero, not a positive acceleration. But then later, when we talked about it, I went back and corrected it, but the acceleration would be what was constant, and not the speed.
I: Oh, so this was something you corrected after the fact, and I just didn't hear anything... [well, I...] verbal.
S: Yeah, I don't think I said anything when I corrected it, but just when we were talking about it, and writing things down, I went back and... and corrected it.
I: OK. Um... OK. So, you... you do think though, I mean, at the point where [Aaron] did the explanation of, you know, there's this acceleration phase at the beginning, you pretty much got the rest of the tutorial from then on?
(Time just after 9:00)
S: Yeah, pretty much. Well, it's just...
I: Was there anything confusing or remaining to be reconciled in your head or something like that?
S: Maybe small things, but, like, once he said that, that was kind of like the key thing.
I: What kind of small things were giving you trouble?
S: Um, like, in part C, I don't know, I kind of wavered back and forth between answers there. When they wanted us to pick which one of these...
I: Oh, this is the intuition refinement diagram. OK. I... your group did get some responses about this, but you personally didn't say a lot of them, so I guess I'm wondering what you thought. Um... what... what was the problem here? You were trying to pick which of these refined intuitions applied to different parts earlier in the tutorial?
S: Yeah.
I: So what was the problem?
S: I just didn't know exactly what they were asking. Because the first one said part B. (pause) Um...
(Time just after 10:00)
I: Above... I think this is formatted in the same way yours was.
S: Yeah.
I: So that one was referring to this part?
S: Mmmhmm. So... which way was I thinking? OK, for that one... (long pause) I guess that one could be either answer, depending on which way we were thinking.
I: Uh, what do you mean, you mean the definition of what net force is?
S: No, the answer to number one [uh huh] could be either... either one of these intuitions, because it depends on what your personal one was.
I: Well, right, so... so for part B, what was your personal one?
S: Um, I think it was this one, that needs to be... to initiate or change it.
I: And this is about the initiation phase of the motion, and you need a net force for that, right?
S: Mmmhmm.
I: OK. Um... and, and which one of them did you think agrees with Newton 2 more?
(Time just after 11:00)

S: Um... (pause) I don't know. I thought it was the one to maintain, but everyone else thought it was the one to initiate.
I: OK. Were... were they convincing to you, or do you still believe that... that this one... this one agrees with N2?
S: I guess I don't really see much of a difference between the two of them, maybe. Like, OK, all N2 says is the force equals the mass times accleration [uh huh], so... I don't know, you'd have to... I could see that fitting with either of those intutitions.
I: OK. So, I've worked with this tutorial before, and I... I don't know, I think this was how these two boxes were worded for you, right, [mmmhmm] in your tutorial? There's a change that we were supposed to make that we didn't. It involves an insertion of the word nonzero.
(Time just after 12:00)
S: Oh, I don't think that was in ours.
I: It was supposed to be, [OK] but I don't think that the change was made, I'm sorry about that. But...
S: Well, that makes a bit of difference.
I: All right, so, given that... uh, which... which of these two refinements agrees more with N2 for you? (pause)
S: Um, it would be this one, then.
I: OK. The one on the right?
S: Yes.
I: OK, and which one of them... so... did... which corresponded with the intuition at the beginning, that you used on the first page?
S: Uh, it would be the one on the left. To main...
I: To maintain? Cause that's what you're doing, you're maintaining, right?
S: Yeah.
I: OK, uh...
S: You gotta make sure the next edition has that nonzero.
I: I've already written a note to the author. I sent the email as soon as I saw the problem was still there. Um... it's too bad it got into the course packs that way, but... um... Another thing I noticed on this part D...
(Time well after 13:00)
S: Mmmhmm.
I: is that one of the people in your group, I think it was [Deena], right? Gave an answer. You were getting lectured by your TA a lot.
S: Yeah.
I: Like, you were, you were ready to leave at this point.
S: Yeah, we were all really ready to leave, all the other groups were done, he just kept talking. We're like, OK, we get it, that's enough.
I: OK, but... the disadvantage, at least from my standpoint, from having one person give an answer, and then him talk for a while, is that I never heard what you think.
S: Mmmhmm.
I: And I never heard what you put down. So, um...
S: He wouldn't stop talking.
I: Well, yeah, I'm sorry about that, but, uh... now that I've got you here, I should... I should probably ask about it. So... the... *sigh* page 1, page 1 answers the question about the part where you're moving at constant speed. It tells you, "apply Newton's law and get the answer," right?
(Time after 14:00)
S: Mmmhmm.
I: The acceleration is zero, so the net force is zero, so up and down have to be the same. Um... you never answered this, so what... I mean, what do you think one of your professors would say was the point of doing the other two? I mean, if you... you already got the right answer by the end of the first page, so...
S: Well... um, we would have to understand that it would need to be greater initially, and then equal. That, like, just... when it was greater, we'd have a... a, you know, positive acceleration, and when it would less, then we'd have a negative acceleration. You don't really get that relationship by just doing the first page.
I: Oh, I mean, it's just applying Newton 2 again, but we didn't ask you about the specific situations of

starting and slowing down that were important. Is it just leaving that out?
(Time 15:00)
S: Well, yeah. The first page didn't talk about starting and stopping, it just talked about what happened in the middle.
I: Oh, OK, so... so the second page and the third page talk about other stages that are important for getting it.
S: Cause you don't move in this world without first starting and stopping.
I: Right. OK. Um... do you... do you have an opinion that's different from... the professor's story you just told me, or...?
S: Just to understand our tuit... intuition.
I: Which intuition do you mean?
S: Well, our intuition about Newton's second law, that it would have to be greater than for... the force pulling upward would have to be greater. That's what you... your intuition says. That in order to be going up, it would have to be greater. But in actuality, your intuition is right, but it's right in the sense that in order to *start* going up, it needs to be greater.
I: OK. Um, I... I understand all of that relates to specific physics questions we were asking. Um... was there a point to this part C here for you, or not?
(Time just after 16:00)
S: I didn't really get much out of part C.
I: Why not?
S: I don't know, it just... I mean... it was... it just, like, reworded it and asked kind of the same thing, it seemed.
I: Reworded what?
S: Well, parts of part B. I mean, we'd already pretty well answered what the net force is needed to do [uh huh], and this was just kind of a rewording of that.
I: So, by here, you had seen all of the physical situations that are relevant [yeah], and, and though about how N2 applies, and gotten the right answer, and understood it, and by this point you didn't need to do anything else?
S: No, I don't think so. I got the most out of this from part B. Part A was, like, a good intro to it, and part B, I learned the most. Parts C and D, was... I didn't really learn anything.
(Time just before 17:00)
I: OK, um... is there anything else? (quiet voice) When were you convinced of all of this, I asked you that. What is your intuition refinement diagram? I asked you that. OK. So we're done with this tutorial. I just wanted to go back and, if you could, could you hold onto that so if I get a chance to Xerox your tutorials later, so I can look at 'em, I could have your responses?
S: Yeah, I want to copy it in my book so it's not...
I: Cool.
S: so messy looking.
I: I'm gonna go back to one of the questions on this survey again, and see if... if your opinion about it changed, or remains the same as it was... and... and you can treat it like I was asking you before, like... if there's a difference between an answer that sounds intuitive to you, and an answer you'd give on a test or the answer you think a scientist would give, let me know if there's a difference.
S: OK.
I: So, this a cable being wound up, on an elevator going up, so check that out.
(long pause)
(Time 18:00)
S: OK, well... I would write on a test that it would be B. The upward force by the cable is equal to the downward force of gravity.
I: Is there... is there still an answer there among those five that makes more intuitive sense than that one?
S: Um... D... D makes intuitive sense. Wait. D or A. Yeah, I guess D.
I: OK. And... I guess... I guess my question is, what do you mean by it makes intuitive sense to you?
S: Just because if you go to pick up something you're... you have to put force into it, and you don't really... you know, you don't really think about it pulling you down as being the same, or else it wouldn't move. I guess it's... the... the intuition falls into more of the initial startup, you know, that you need to put more force in initially, and you don't really think about after it's started what happens.

(Time well after 19:00)
I: So you're... you're connecting your intuition directly with the experience of starting it...
S: Yes.
I: Even when we ask about constant speed?
S: Yes.
I: OK, I guess... I think I see what you're saying there, that's interesting. (pause) Um... (any other?) specific ones... (pause). Check out twenty... 25 here is a horizontal case. A constant... a woman's pushing a box with a constant force, and the speed is constant. So what can you... what can you say there? Of course, for obvious reasons, the elevator one was the one I needed to ask you first, but...
(Time just after 20:00)
S: Yeah. (pause) Um... I... I'd say it would be C. It has the same magnitude as the total force which resists the motion of the box.
I: And that would be...
S: That would be what I would write on a test.
I: A scientist answer, if you want. OK. Do any of those answers seem more intuitive than that?
S: Well, the same one as before. It would have to be greater than the, uh, the total force that resists the motion of the box. D.
I: So this... this is the... this is the same thing, just horizontal?
S: Yep.
I: OK. Um... well, what happens... so 26 now, what happens when you double the push?
S: Um... (long pause)
(Time 21:00)
S: I suppose it would be E. It would... continue at an increasing speed. Just based on the tutorial from today.
I: Um... what... what part do you mean?
S: Hm?
I: What part do you mean?
S: Um... part B, when we talked about... yeah.
I: That? The initiation stage? Or rather, if... if the force remains larger... OK, so... it's the same thing. All right. Let's see, I don't think I need to ask the last one.
(muttering and shuffling papers). Yeah, there's no other one on this that's as relevant as the elevator question, so if I asked you that, it's probably enough.
S: Yeah, I remembered that in the tutorial, and I thought, "He's gonna ask me about that, isn't he?"
I: Well, you thought right.
S: Hehheh.
I: Yeah.
(Time just after 22:00)
I: Pretty soon we're gonna get to tutorials that don't relate to stuff on this thing at all.
S: Uh oh.
I: So...
S: What are you gonna do?
I: I don't know, I'll have to think of something else. Give you a new survey. No.
S: Yeah.
I: Um... but yeah, I think... what time is it now, do you have a watch? Probably gone less than a half hour, that's fine.
S: 4:14.
I: Yes, that's cool.
(end tape)

Interview 5: Free-body diagram tutorial

The purpose of this tutorial was to get the students to see that free-body diagrams are not just annoying requirements made by teachers, but that they are occasionally useful ways to organize thinking. Sometimes, a problem will NOT require such a diagram for completion. Patty's group had a strong emotional reaction (often negative) to certain elements of this tutorial.

(Time 0:00)
I: You can get hooked on it. Sort of takes over your life.
S: I've just been wanting a Pepsi all day. [I *laughs*] And like, every machine I went to was sold out. So I finally went to that little place where they have stuff. Even though they charge, like, an extra quarter.
I: Mmmhmm.
S: So...
I: The, uh... the last thing I got from there was an orange Mountain Dew, and that was nasty. It tasted like one of those... uh... one of those popsicles you can make yourself in the freezer, [yeah] but it's, like, the liquid stuff that's beforehand, so it's totally vile.
(end off-topic part)
I: All right. Um, I'm debating how to do this because the part I got to in the tape was, uh... probably like five... five or ten minutes before you left, so I saw the important parts of the tutorial, but the last thing I saw was your group basically getting very upset.
S: We were.
I: Um...
S: Like, I dunno.
(Time 1:00)
I: Anything specific here you'd care to talk about now? There's some things I noticed you made comments on, but, um...
S: Well, it's... I don't know, we're being asked to find all the purpose of doing these things, when really we just need to learn how to do them, you know?
I: W... where do you mean?
S: Well, like, the whole title! What's the purpose of a free body diagram?
I: Mmmhmm.
S: Well, we don't really care what the purpose of it, we just need to know how to do it. I mean... and you kind of pick up why you're doing it as you learn how to do it, but the whole focus of this tutorial was, like, what's the purpose of it, instead of teaching you how to do it.
I: Uh, what do you mean teaching you how to do it? Like, how... how to label it correctly, how to... OK. One of the th... one thing about that, I guess, you were, let's see... this is page 3.
S: Page 2 is on the back of that.
(Time before 2:00)
I: Page 2 is on the back of that. OK. Um... you were asked here in this problem, "was it helpful or not to... to draw it," and you said no. To draw a free body diagram, right? So, finding the acceleration by lumping them together, you didn't need a free body diagram to do that.
S: No.
I: Um... (pause) let's see, uh... was the free body diagram helpful for... um... the second problem, for deciding if the whole 200 gets transmitted to box B?
S: Perhaps a little bit.
I: OK.
S: We had a homework... our last homework, we had to draw some free body diagrams, and I found them helpful on the homework, but...
I: OK, uh... and... giddy-up, very nice (reading the paper), and you... you drew... how much of this horse problem did you get through?
S: We didn't really get through much of it at all.
I: Didn't get through much of it? Can you describe the homework problem... uh... where you had to use this stuff before and it was helpful?
(Time after 3:00)
S: Well, there were two homework problems on our last homework.
I: Uh huh.
S: Um, I think I have it with me, if you'd like to see it. There was one where there was a book on a

string that we had to draw, like, a free body diagram for. It was... numbers 4 and 5.
I: I'll just say this for reference on my tape. It's homework 4 on [Professor]. Numbers 4 and 5. Right. So one of them is pulling a book, another one is a ball on a ramp. OK, how were the diagrams helpful in doing those questions?
S: Well, let's see... they just... they wanted to know things like coefficient of friction and... where the... which way it was going, or something. I don't know, it was just cause it felt like... maybe they were really helpful because here we were dealing with a... a diagonal force, which was hard to understand at first, and drawing the free body diagram, we figured how the diagonal fit into the horizontal and vertical, whereas this problem in the tutorial, it was pretty much all horizontal, so... you don't need a diagram to figure that out.
(Time well after 4:00)
I: OK. Um... let's see. Now, let's see... (pause) I know, I know you... your group did not see questions like this first one as being that helpful, am I... am I getting that right?
S: Yeah, we... (didn't get much out of that?)
I: OK, but I want to at least see what you... what you said to it here, because, uh... other people in your group, I think it was [Aaron] and [Deena], or something, were... they were responding to it. They were saying that both of these people were making good points, but they weren't saying which one... which points they thought were good or which they thought they agreed with. Uh, and I'm wondering maybe if you thought the same thing. Let's see what you said. "I agree that the diagrams communicate what we know to the TAs, and let them know we need help with. However, I think they're primarily for us to teach us what's going on. It's important for students to do them and label them correctly, cause they're part of the assignment. Students should also know what they mean." OK. So part of the... I mean, so, this is what you still think about them, basically? Did that change over the course of doing this?
(Time well after 5:00)
S: Um, I still think that [mmmhmm], except for during the course of the tutorial, I like doing them less, I'd say.
I: Why... why is that?
S: I don't know. Like, I guess doing the tutorial made me agree more with the second person, where it's OK to skip 'em if you don't need 'em, because it's kind of like [mmmhmm] you just don't want to do it if you already understand it.
I: You seemed to have a bit of a spat with one of the TAs about labeling and things... do you remember what I'm talking about?
S: Yeah, well, I didn't see what the big deal was, and he just... I don't know, like... OK, yes, you have a... a method for doing things so they're not confused when you have publications, and... but in teaching something, like, that's the first thing you looked at... is that we picked a different variable? I mean...
(Time after 6:00)
I: You mean a different letter for [yeah] one of the specific forces?
S: I mean, that... that doesn't matter at all as far as, like, do we understand it or not. And that was, like, the one thing he honed in on. And I'm just like, look at the diagram, don't look at the variable that [Aaron] happened to pick [hm]. And even if it's not perfectly correct, he had a good reason for it, so...
I: Mmmhmm.
S: And then [Aaron] was saying later that his reason for it was in lecture, that that's the variable they used, so... why would he not use it?
I: Right.
S: But... I was...
I: Yeah, I think... I think the TA was suggesting something like using the letter capital F instead of an N [yeah], or a W, or something like that. Uh, I am a little surprised he said that, cause I remember the exact same slides for this, and, I mean, that's how we labeled them in previous semesters..
(Time just after 7:00)
S: You used an N, or an F?
I: Well, depends on what the force is, if... if it's a... if it's a normal force, like, a touching force pushing, then you use an N, if it's a weight, it's a W, so since you're using the same slides we used to use, I'm sure those letters are the same. But, I mean, that kind of little thing is maybe why you don't like using them as much anymore?

S: I don't know, I was kind of irritated with the assignment, and then he came over and picked on something that didn't even matter, so that's why I...
I: OK.
S: had a spat.
I: Um... about... OK, so about some specific physics stuff. Um... you had an idea at the beginning that these boxes would split [mmmhmm], remember that? Um... do you remember why you thought that or why you still think that, if you do?
S: Well, just remembering, if you're gonna push two things that are on wheels, when you start up, there's... the one... the smaller one's gonna go faster. Like... I don't know, I just seem to remember doing that with stuff, like...
(Time after 8:00)
I: Yeah, what's the physical situation you're thinking of?
S: Well, I'm thinking of the initial startup, and I guess this whole time, we were talking about "already in motion."
I: OK.
S: And we... actually, I remember, we did that in tutorial a couple weeks ago, maybe last week, or something. Yeah, it was last week, with the well, where the initial tug or the initial push is gonna be stronger, or be different in some way than the constant speed. But...
(pause)
I: OK, so... the idea you had in your head for a specific situation was the initial push?
S: Yeah.
I: But you're convinced for this problem, we're talking about... after the initial push?
S: Yes.
I: OK. This isn't at constant speed, does that make a difference?
S: Um... I don't know.
I: I mean, you said there was an acceleration, right?
S: Yeah.
(Time 9:00)
I: OK.
(pause)
S: Well, I guess it's a constant acceleration, right?
I: Mmmhmm.
S: I guess that would make a difference. I suppose a difference would be made if the acceleration was not constant. Then the box would be... the boxes would be splitting and coming together, banging into each other.
I: OK. Now... the... an impression I didn't get from you watching all of this, um... was that... uh... (pause) What I didn't get was what you thought about solving this... this problem, you know? Figuring out how much force goes through to box B. Um... [Aaron]'s idea was that you have to lump them together, right? And that's how you solved it eventually.
S: Mmmhmm.
I: [Annette], right, she's the one next to you...
S: Yes.
(Time 10:00)
I: She was very bothered throughout all of it. Um... her... her idea was that, you know, if... if... if all of A on B is 200, and then B on A is also 200 [mmmhmm], then that means A isn't feeling anything. Do you feel you worked that out? How do you work out that point of view, or is it not even worth thinking about that?
S: Well, it was something we did in a previous tutorial, where it's just... the forces are always equal and opposite, yet something can still move.
I: Mmmhmm.
S: So... (pause) I think it was tutorial 4. I don't know, but it just...
I: It was last week? Timmy and the well?
S: Yeah.
I: So there's no net force on Timmy, and he can go up at a constant speed?
S: Yeah.
I: OK. But, I mean, is that a problem, though, because in this diagram, you know, A has the hand

force pushing on it, which is how big?
(Time 11:00)
S: 200.
I: It's 200. And what [Annette] was pointing out was if... if all the 200 made it through to B, then this force from B back on A would also be 200.
S: Mmmhmm.
I: OK, so A has no net force on it.
S: Mmmhmm.
I: But A has an acceleration.
S: Right.
I: So... I mean, did you work out eventually how... I mean, was it worth talking about that, or... I mean, you got the answer right by lumping them together, is that good enough?
S: Um, we really didn't talk about it much, maybe cause we were all in a bad mood or... I don't know, we didn't finish it, so we were trying to hurry up and finish it without spending too much time explaining things.
I: Mmmhmm. OK. Uh, you... you actually had an idea at first that not all 200 made it through to B.
S: Yeah.
I: You remembering that, right?
S: Yeah.
I: I think... I think it's something about... uh... you said that... that the boxes are different masses, and so, if they're different masses and the same acceleration, then they have to be experiencing different forces. Then you noticed that we asked for something like an intuitive thing, you know, without any calculations for explaining it. Can you think of one, or is that the only justification that you can think of for [well]... not being 200?
(Time after 12:00)
S: Experience... if you're going to move something heavy, and then you're going to move something light, I mean, you're gonna have to push harder to move the heavier one the same speed than you're gonna have to push to move the lighter one the same speed.
I: So the light one shouldn't need as much [right] force? OK. (pause) All right.
S: Then I did the problem wrong, cause I did the calculations.
I: What do you mean?
S: I didn't read the whole problem, I just, like, did the calculation part, and then I continued to read the problem, and I was like, "oh. We weren't supposed to do the calculation part."
I: OK. Um... as... as it turns out, though, this is exactly right, though, isn't it?
(Time 13:00)
S: Mmmhmm.
I: Yeah, 50 Newtons is exactly right. OK. Um... your group as a whole seemed to think, like, around this point, I think it was [yeah] that we were repeating questions, or asking you the same things over and over again?
S: Um...
I: Do you remember anything like that or was that... was that a different part?
S: Yeah, I remember Andy saying something like that, I don't know exactly which question he was referring to, but I remember it was around this part.
I: Mmmhmm.
(pause)
S: I think maybe here, because we were asked what the net force on A was, and we just figured it out in this part.
I: OK, you may have figured it out here, but you did... I mean, we didn't explicitly ask you what it was here... until...
S: I think it was on this side they started asking the same thing. (pause) I don't know. Maybe not exactly the same, but just very similar things that we're like, "OK, we get it, can we move on to something else now?"
I: OK, um, you have... you have here for part iii (little three) here, accept/reject. Now... and after this... um, after this was when, you know, the group started getting a little restless. Um... what does this mean?
S: I wrote "accept" down at first. I didn't really understand what it was asking, and then we decided it

was "reject," so I wrote "reject." I probably should have crossed off "accept," but I wasn't... I wasn't sure at the time.
I: I mean, are you... are you sure now?
S: Yeah.
I: Do you know which one of those you mean?
S: Yeah, reject would be my answer.
I: Why?
S: Well, because we're not saying that... well, see, maybe this was my confusion, because I didn't know... what assumption... if this was... I didn't know what this question was in reference to, or if it was just in reference to nothing and saying that the force A on B is fif... 200 Newtons. So, I'd accept, or rather, I would reject the assumption that it's 200 Newtons for A on B.
(Time after 15:00)
I: OK. So you reject it at this point?
S: Yeah.
I: All right. And... and actually, you found out exactly what the force of A on B is.
S: Mmmhmm.
I: Uh...
S: I think maybe this was my confusion, because, like, I thought it was 50 back here [oh], and I was still accepting...
I: Back, uh, part B/C before the checkout.
S: Yeah.
I: OK.
S: I thought it was 50 there, so I was saying I still accept it's 50. But then I wasn't sure exactly what this question was asking, so...
I: Mmmhmm. And you didn't care... the free body diagrams were not helpful at all [not really] for this either? OK. Um... so, the one other thing I want to comment about, and again, I don't know if these were your exact words, but they were words given by people in the group that, you know, you felt coming out of this like you didn't understand what was going on.
(Time after 16:00)
S: Yeah, pretty much. I don't know. It was kind of a long tutorial [mmmhmm], for... and it didn't really teach us as much as it could have. Like, I felt like it spent a lot of time on extraneous stuff, and it never really got to the heart of understanding it. And maybe if it did, it got to the very end, where we didn't get the time to finish it.
I: OK, well, I mean, these things are long, and, you know, whatever main point... you're supposed to get to before the very last page, cause we know people don't get to that.
S: OK.
I: Um, so, what stuff do you feel was left out?
S: Well, it's probably just grasping the concept of how the force is distributed over the two boxes, and how it's also, like, how they're treated similar and how they're treated different, and... like... just, like, maybe where these forces are going, and maybe the tutorial could've used the free... the free body diagram more. It just... I don't know, like... (pause) questions where we have to... read about these two assumptions and write about it, that was kind of a waste of time. Or, you know, you could just as easily accomplish this by saying, like, here's some reasons for doing it. A, B, C. And keep that in mind. And, I don't know, just... there's... there's so many, like... just, like, "think about this" questions in these tutorials instead of, like, "figure it out." Like, they always want you to, like, think about it intuitively, and just, like, wonder why you're wrong, and then finally, they'll get to the main point and then you'll be like, "oh, OK." But sometimes, you don't get to that main point. So, I guess that was the main problem with this one.
(Time just after 18:00)
I: So, so... I mean, what... do you think there was a main point in this that you didn't reach? Or...
S: Yeah, I kind of feel that way. Maybe just cause we didn't really resolve anything at the end.
I: I mean, you didn't? The question was... uh... I mean, here, you're talking about two boxes, and will the glassware in this one break? And, you know, you played this... this little game, you know, if... if one force is 200, then what's the net force? You reject it then.
S: Mmmhmm.
I: And in the end, you got the right answer. And you actually, you had the right answer before.

S: Yeah, but [Annette] didn't understand it at the end, and we didn't really have time to talk about it and explain it and make sure all four of us were on the same page. Like, I think I understand it, and know what's going on [mmmhmm], but, like, I understood at the beginning that they were gonna be distributed differently because they were different masses.
I: Yeah, if you... if you take... what's... if the force A on B is 50, then what's the net force on A?
(Time just after 19:00)
S: I think that would be 150.
I: 150, and is that consistent with the two different sizes getting different forces for the same...
S: Well, sure, they're... the mass of B is one third of the mass of A, so it makes sense that the forces would be one third ratio.
I: Part of what I'm trying to get is a lot of what the group was saying, and... you know, I understand that, you know, that [Annette] wasn't understanding it in part, she was the one that you had to try to explain it to most. But a couple of you, not her, even [Aaron] was saying stuff like this... was that, like, you know, he took physics in high school and was really good at it, [yeah] and now they're not doing anything. But if you got through this, then you did everything right. So, I mean, I'm just wondering what... what aspect of this gives you that sort of [well, it's like] ugly feeling in your mouth.
S: I think it's all the intuition stuff. It's like they're trying to trick you. Like, we know that things are counterintuitive, but instead of focusing on how they're tricky, let's focus on just learning them. And... as [Aaron] was saying, like, the way that they teach this course, it different... they're going through this really different thing, and, I mean, we've been in school now for what, like, 15 years, most of us, and we're pretty well set on learning certain ways, and you go and change it after 15 years, it's kind of hard.
(Time after 20:00)
I: Hm.
S: So it's frustrating when he... he's learned physics one way, and he was good at that way, and he understood it. And now he's trying to learn physics again in a different way, and it's hard, because he's not used to that method.
I: Mmmhmm.
S: So, I mean, all... all we really want to do is learn the material, and pass the class. And you wanna learn the material in the easiest way possible, and maybe you're, like, doing this new method of teaching to make it easier, but in reality, in the meantime, in the transitional stage, the change is just making things harder.
I: OK. Um... what about for you? I mean, you never had this sort of first way of doing it.
(Time just after 21:00)
S: Well, I've never taken a physics course before [mmmhmm], but I've... I've usually been taught in the same way of... this is what's right, do it this way, any questions on why we do it this way? Instead of, like, what way do *you* think we should do it? And then, nope, you're wrong.
I: Wait, where did we ask you that? Which way do you think we should do it?
S: Well, I mean, all the intuition stuff. Which way does your intuition say we should do this? Like... that's a common question in all these tutorials. Intuitively... figure this out.
I: It's intuitively predict.
S: Yeah.
I: Is that... is that the same thing?
S: Yeah. Predict it intuitively.
I: And you're never right?
S: Well, if you are, then you're not, like, thinking intuitively according to... cause you're, like, using prior knowledge, which... I don't know, like, they want you to get it wrong when you do it intuitively, so they can, like, prove you wrong. And it's just... it's kind of annoying...
(Time after 22:00)
I: Seems kinda mean? *snicker*
S: Yeah, well, that doesn't really help us. It's like, "haha, you're wrong," we're like, "OK, now you gonna tell us how to do it?" And the TA's like, "Well, just keep going and you'll figure it out."
I: OK.
S: OK?
I: Um... one thing I can preview for you is... I mean, you're gonna be asked to give intuitive answers in future tutorials, but they will be right a higher percentage of the time. Now, when you did Newton 3 a couple weeks ago, remember, with the car hitting the truck? The second part of it, we said... truck hits

a car, and the... the weight difference... the weight's different by a factor of two. And so the truck slows down by 5. So intuitively, how much speed does the car gain in the collision?
S: Mmmhmm.
I: Do you remember your answer to that?
S: Oh, I said something different, like, it would gain the same amount, or something like that.
I: It would gain five?
S: Yeah. Cause, like, instead of...
I: Ten turned out to be right, though.
S: Mmmhmm.
I: Wasn't it?
(Time 23:00)
S: Yeah.
I: And is that... does that not seem like it could be an intuitive answer to you?
S: It does, but... when they ask you all the time, "think of this intuitively," and then ha ha, you're wrong... so then you start, like, second guessing yourself every time. Even if what you had was right, you think, "well, let's see... that can't be right, or maybe it can be," so it takes you a lot longer to arrive to the same answer.
I: Mmmhmm.
S: It's just... it's frustrating. And I think all four of us were really frustrated today. Maybe for slightly different reasons, but... I don't know.
I: OK. Um... so (flips papers - pause), I just wanna... since I didn't hear you talk this out, I'm just gonna read this part of 2H. Uh, I don't even know if I need you to comment on it. F A on B is F of Student on B. Uh... do you agree this rule is an arbitrary choice? You have to label it F A on B cause A is touching B. So if I... if I labeled it student on B, it wouldn't screw me up? I guess that's my question for you.
(Time after 24:00)
S: Um...
I: If I labeled the force on B the force of the hand on B, would that screw you up in solving the que... the problem?
S: I guess it would, now that I think about it. Because that's actually a different force. I mean, I don't know if it's correct wording to say this, but the force of the student... a lot of that is absorbed by A, and so when... the force that's on B is not the same as the force of the student.
I: If I labeled it student on B, it might mislead me into thinking that it's all 200, maybe?
S: Right.
I: It's a different force, we have to treat it like that. OK, and then you didn't really get to the horse stuff, right?
S: No.
I: Well, (pause) I know it won't completely convince you that we're trying to be nice about it, but in previous years, this horse question came first. Um... and we found that drawing the free body diagrams and talking about it was so confusing and took so much time that, you know, it was... it was more dwelling on this question, and they have no time to get to this part with the boxes. Did you get anything out of doing the hourse question, or not? I wasn't able to...
(Time well after 25:00)
S: Seemed like a repeat of the boxes. Um... maybe a little different because, like, if box A is the horse and box B is the wagon, then box A is the one exerting the force instead of having force exerted on it. But... we didn't really get to it very much. It's... maybe this was the part [Aaron] was annoyed about, cause this seemed very repetitive with the boxes.
I: Well, um... I mean, all the stuff that I'd seen him get upset about with the repetitiveness was actually before you got to this question was actually before you got to this question, so... I mean, he might have been...
(Time 26:00)
S: Cause he was looking through it, I think, a little bit when he was commenting on it.
I: Oh, I didn't think about that.
S: I think... I think he was skimming the... the next pages.
I: I've gone through all the relevant stuff talking about this. I guess there's one other thing. There was a comment made that... that the questions that are being asked of you in the homework aren't like real

problems?
S: Yeah, I forgot who said that.
I: I think maybe [Annette].
S: I don't know. I like the homework questions better. Or at least... I don't know. Sometimes. This last one, this last homework, um... like, drawing the free body diagrams...
I: Mmmhmm?
S: They were difficult, I had a good friend of mine teach me how to do them. So I learned a lot doing that, but...
I: Did you do all that before this tutorial, or...
S: Yeah, this was due Friday.
I: Oh, of course, you just did the tutorial.
S: Yeah.
(pause)
(Time 27:00)
I: So, um, was there anything you... you felt you learned about dia... free body diagrams from this that you didn't pick up from the homework questions already?
S: No, because the homework questions were more in depth. They dealt with vertical, horizontal, diagonal forces. [OK] And this was just dealing with horizontal, so it was pretty repetitive of the homework, and simpler, so I didn't learn anything new. If this was given before the homework, then I might have learned something, but... it was just kind of a repeat of the homework.
I: OK. Uh... trying to think now. Yes. So far, stuff I've asked you about the tutorial, is it... is it been pretty easy to remember what I'm talking about?
S: Usually.
I: Usually?
S: I can't always remember exactly who said stuff, but...
I: I... I don't know from your perspective what you think of this, that, you know, I'm someone that wasn't there, all of a sudden, you know, you come talk to me, and I know everything you guys did. That isn't excessively freaky, is it?
(Time after 28:00)
S: No, but, I've like... I'm aware of it while we're doing the tutorial now, I'm like, we're being watched instead of just...
I: Well, at least you're not explicitly saying that.
S: No.
I: Um, something I notice is that, you know, the rest of your group by now talks as though they don't care. And, I mean, they shouldn't, cause, you know, I don't talk to your TAs about this. But, the neat thing is is that... I've talked to students about tutorials in the past, and it's usually been 2, 3 weeks after they do it, and so, by then, I mean, it's all gone. They have another tutorial [yeah] they've already done. Um... but... OK. I mean, can... you... you say you're still kind of aware that the tape is there? I mean, do you think it's sort of behavior altering? I... I think it looks pretty natural so far, or at least, what I've seen, but...
(Time just after 29:00)
S: Well, that's good.
I: Um...
S: I guess I'm more aware of, like, not to pick my teeth, or anything like that.
I: Oh we, well, we don't use stuff like that, but... all right. Um... anything else about homework questions, or stuff about the tutorial you have to comment on that you haven't gotten a chance to yet?
S: Well, I'll have to say for the class so far, like, I learn by seeing and doing, that's just the type of learner I am. And...
I: What do you mean, "seeing and doing?"
S: Well, like, visually, like... when teachers lecture, a lot of them will lecture more for the visual learner, and they use the board a lot, write down a lot of things, and hand out stuff. And, whereas others will... will speak a lot, and, you know, narrate and just... and, a good professor will do both, because he knows he has both type of students. Because some people just learn better by hearing. It's just... but, um...
(Time just after 30:00)
I: So, what are both things?

S: Well, seeing and hearing.
I: Oh, so it involves writing stuff and talking it out?
S: Well, it's good if you're going to write things, but some people, they just... they don't learn it as well unless they hear someone say it out loud.
I: Mmmhmm.
S: Whereas another person won't learn it as well unless they see it written.
I: OK, so, I mean, go on...
S: So, like, myself, I'm more of a seeing... a visual learner, so, like, doing tutorials and homeworks where I'm seeing it and writing it has been a lot more helpful than lecture where I just listen to the professor talk.
I: Yeah.
S: So... I guess that was all I wanted to say.
I: So... hm. So, you think you are getting something out of the tutorial, I mean, at least, moreso than lecture just because of sort of the delivery? Or the...
S: Yeah.
I: OK... personal preference.
S: Yeah.
(Time before 31:00)
I: OK. Um... all right. We'll see how the next couple ones go. I'm trying to think if there are anything with complicated force diagrams in it or not, I'm not sure. But, anyway, you'll see that as we come to it. And I will stop this here...
(end tape)

Interview 6: Momentum and work tutorials, and a test discussion

This interview was originally called "Interview 7" because we had to skip a week and we briefly discussed two quick tutorials in this one. The momentum tutorial has the students come up with the p = mv formula and use it. The work tutorial discusses the meaning of physics work versus the common-sense definition. We also discuss how the class has been going, as well as an exam she had recently taken.

(Time 0:00)
I: Knocking stuff over... uh... we don't need to talk about this for a long time, but do you have the one from last week, too?
S: Yeah.
(pause)
S: Tutorial number... 5. No, 6.
I: 6.
(pause)
I: So... you were in...
S: A different group.
I: You were in a different group. Um... anything interesting to report that you remember from doing this? This one, then?
S: Um... well, it was a different group, so it was a bit different, but... let's see... just interesting, we were... different... same size, and different sizes, and how that relates.

(Time 1:00)
I: OK. Your group didn't have any trouble coming up with an equation that... for... well, oomph, that we called momentum that worked out?
S: No. And Colin was in that group, and I think he's had a lot of physics before, so...
I: Colin's a different student in the class?
S: Yeah. He's... well, I don't... I don't guess you get to see very many other students.
I: No, I don't know... I don't know who that is at all.
S: He's probably one of the most outspoken students in the class.
I: In the whole... in the lecture, too?
S: Yeah, actually, in the lecture.
I: K. Um... and he was in your group?
S: Mmmhmm.
I: Uh, so...
S: I think he's had physics before, so he's... I guess, bored with the subject, cause he knows every... all the equations, and stuff like that.
I: Well, I think 80% of the class has had physics before, actually, [yeah] if not more, but... all right. So. I mean, you got all these mathematical numbers right, I think.
S: Mmmhmm.
I: Um, you have, actually, for number one, uh... and maybe this is something about the beginning of the tutorial, but you have numbers one and three circled. Let me try to remember if they say the same thing. Formulas are more of a problem solving tool than a sensemaking tool, but in general, physics formulas express some kind of common sense ideas. Um... how did you circle them both? I mean...
(Time well after 2:00)
S: Well, I circled... um... I don't remember which one I circled at first.
I: Uh huh.
S: Maybe I circled number one first, and then I saw that my groupmates had number three circled, and I thought, "oh yeah, well, that makes sense, too." So I circled number three after I saw what they had.
I: OK. Um... well, I mean, I guess... which... which do you agree with? I think the thing where one and three disagree are, uh, what formulas are for. I mean, do they either express some kind of common sense ideas, or are they more for, uh, solving problems than making sense of it?
S: Well, I guess that's why I circled them both, because I saw formulas as both.
I: Oh.
S: As making sense and also problem solving.
(Time just after 3:00)
I: Hmm. All right. Um... let me just see...
S: You don't see 'em that way?
I: Oh, I... I don't see them a particular way at all, it's just... the reason I ask the question is because a lot of people think that, you know, the statements one and three contradict each other. You know, one of them... one of them says that formulas are more for problem solving than making sense of it, and... three says, you know, they express some kind of common sense ideas, but you see some truth in both.
S: Well, there wasn't an option that says they are common sense and useful for problem solving.
I: Fair enough. OK. So I've... I've seen that too, but I was just making sure. Uh, I mean, I wasn't agreeing or disagreeing at all. Um... (muttering) they stopped... diagram... you did a 3.5. OK. I'm just going to read off what... what the last question in section B says. What agrees with Earnest... common sense is useful, the equation states common sense in mathematical terms. Um... hm.
(pause)
(Time after 4:00)
S: That's going actually back to the very first question. How common sense and mathematics are related in a formula.
I: Cause there's common sense in there, but it gives you the math that you need to actually solve the thing?
S: Yeah.
I: OK. Um... this tutorial usually goes pretty quickly for groups. [Yeah, we were...] And it sounds like for you that it was just... go through it. So...
S: Probably only took us like twenty minutes.
I: OK. And you... you had not seen... had you not seen this momentum formula before? Is this

something you were unfamiliar with?
S: Yeah, that was new to me.
I: That was new? Um... but...
S: It made sense, so...
I: But it made sense. And, I mean, you came up with these answers here for twice as big and seven times greater, I mean, those made sense to you, right?
S: Mmmhmm.
(Time just before 5:00)
I: Um... now, I guess in previous tutorials, you had reason to doubt that, you know, your first instinct was right. Um... like, you know, about the two things colliding, one exerting force... more force on the other. Or Timmy in the well, you might have thought, you know, you needed more force to keep him going up at constant speed. But, uh, I mean, is there a reason you can think of that there was less doubt for, um, you know, this twice as big, this seven times as big? These... these little steps that you did to get p equals mv?
S: Well, um... I think it might have had something to do with that I was a little less familiar with this, like, pulling something with a rope, I've done that before, it always seems like you need more force. It just kind of seems that way, and in fact, we were talking about that you did need more force initially.
I: Mmmhmm.
S: So things like that. And this one, like, I wasn't as familiar with, cause... well, maybe I was slightly familiar with, but as far as whether it was exactly half or not, I didn't know, so... I just thought, you know, why not?
(Time just after 6:00)
I: Hm. So, it's like with this oomph stuff, there wasn't a... you know... a distracting real life example?
S: Yeah, I guess so.
I: That could have given you the wrong idea? OK. Um... like I said, I just wanted to see what you did with this, but since I couldn't watch you do it, and since you did it pretty quickly, we don't need to... we don't need to dwell on it. Of course, focus on this one, mainly. If there's time at the end, actually, I have a question for you about... about how the test went, cause it seemed like your group had some choice comments about it, but...
S: The whole class did. In lab, we were talking about it, too.
I: OK, well, I mean, if... if there's a little time at the end, I'll see what they are. Specifically, I think there was... um, there was, like, one specific question that everyone was complaining about.
S: Well, he only graded the first one, so that's the one we were talking about.
I: Who graded the first one?
S: Our TA.
I: The TA? Um...
S: And that was also the hard one.
I: Oh. So that was the one... so that's why you were talking about it with him? Cause that's the one that he graded, and you know, he knew?
(Time just after 7:00)
S: Well, he's going to grade them all, but he only got through grading the first one.
I: He is?! Huh.
S: I think so. I don't know, he's a pretty slow grader, so...
I: This is... this is for [Professor]'s class, right?
S: Yes.
I: OK. I think the way is done is that the test is separated, and a different person grades each question.
S: OK.
I: There was an estimation question on it, right?
S: Yes.
I: Something about a... like... filling a football field with trash?
S: Yes.
I: OK. Yeah, someone else graded that, and Dr. [Professor]'s gonna grade the essay, so these are all divided.
S: Oh, OK.
I: So, right. So, you won't have to wait for... for Brian to grade the whole thing. That would take too long.

S: OK, cause the way he said it, it sounded like he was grading the whole thing, and he'd only gotten through the first one. I guess he was saying he's only graded the first one.
I: OK, so... going on to this tutorial 7, work and energy, um... your... your group this week seemed to move pretty smoothly through most of it.
S: Yeah.
I: Was the first page just super easy for you?
S: Pretty much.
I: Um...
(Time 8:00)
S: I've done kinetic and potential energy before, so...
I: Oh. Where?
S: I don't know. Middle school?
I: I guess... I guess you do talk about it then. Um... had you done it enough then, OK... no, I guess I'm not on the second page yet.
S: Well, I understood the difference between them.
I: Right.
S: And I knew, like, these definitions, so...
I: That... that, uh, kinetic energy involves motion... potential energy depends on how high up something is?
S: Yep.
I: OK. And... your whole group was pretty comfortable with the, uh, the biology question?
S: Yeah.
I: Were you surprised to see that?
S: I was happy to see that, I was like... it's something nice, instead of... all this dry science.
I: OK. Or, at least this was something that you were more... I don't know... that you knew more about than the TA, let's say, right?
S: Yeah.
I: I saw that he made some kind of comment about that he didn't know what ATP was.
S: Yeah, well, [Deena]... he asked what we wrote, and she just said "ATP," and he had no clue what that was, so it was like, "wow, all four of us know something that you don't have a clue on."
(Time after 9:00)
I: Well... if it makes you feel any better, it's probably not the only thing, but... all right. Um, so, I guess, when you had been exposed to potential energy before, did you... did you know it as far as this mgh equation goes? Did you know that before?
S: No, I don't think so.
I: OK, um... I mean, was the way this was presented... did mgh, you know, make pretty good sense to you once you went through all this.
S: Yeah.
I: OK.
S: I mean, they could have just given us the equation, and told us how we got it, and that would have been OK too, but the point of this is kind of work it out yourself, so...
I: So, [Professor] in class could have, you know, drawn the same thing, and drawn the forces, and gotten the same answer, and you'd be fine?
S: Yeah.
I: OK.
S: Well, I... I pay more attention during tutorial, because, like, we were writing stuff and talking with a small group instead of a lecture hall where, you know, you tend to zone out. And I don't even know if he's done this in lecture before.
(Time after 10:00)
I: I mean, maybe not, but that's just a question of when he gets to it. All right. So, for people who already knew the formula, the purpose of parts B and C is to annoy them. Um... *laughs* OK, I know that might not be serious, but were there other people at the table that... that knew it?
S: [Aaron] knew it.
I: Yeah, I think he might have... I thought he might have. OK. Um... I couldn't tell if he looked bored or not. Bored or annoyed, did you think he was?
S: Uh, I don't know. He was his usual physics of... can't wait to get out of here, but let's go ahead and

do this. I don't think he was any more annoyed than any other lab, or any other tutorial.
I: OK. Um, now, let's see... pushing on a wall... just one comment that you made I wanted to clarify, right, it was C. Maybe you wrote more, but... when you push on a wall, are you doing useful work, or wasting energy? So it depends on your purpose for pushing. If you want to just sweat, it's useful, otherwise, it was a waste. So, as far as just sweating goes, like, so you're... decide to work out [yeah, sure] by pushing a wall, OK. So if that's your purpose. All right.
(Time well after 11:00)
S: It depends on your definition of the word "useful."
I: Right, what... what do you think the definition that, you know, this worksheet meant?
S: Probably meant moving the wall.
I: Or doing something.
S: Yeah.
I: Actually, you know, accomplishing something other than just, uh... working your muscles out.
S: Mmmhmm.
I: OK. Um... now, I wanna look at this consistency check, too. Now, you see the student's idea... um... let's see. In everyday life, doing work means the same thing as expending energy. So does the student's idea that doing work means expending energy mesh with the rough definition of work given to something? You said no. Hm. How, how are those inconsistent?
(Time after 12:00)
S: (mumbling) student's idea... (pause) What's your question?
I: Well, you were asked to check for consistency between intuition and definitions. So you said they're not consistent... the student's idea that doing work means expending energy and the rough definition of work that you got on the first page.
(pause)
S: Well, I don't think they mesh with each other. Oh! Mesh! No, I meant to say yes, I'm sorry.
I: Wait...
S: I took, I took the wrong definition of the word "mesh."
I: What do you think "mesh" means?
S: I thought it meant, uh... like, mess... like, mix up or go against. But it means...
I: It means, "go together with."
S: Yeah.
I: Right. Wait, you think these go together? They say the same thing?
S: Yeah.
I: Hm.
(Time 13:00)
(long pause)
I: OK. I guess I didn't want to dwell on that. (not sure which one this means)
S: We didn't spend much time on it.
I: Yeah. Um...
S: We said... we spent more time on the equation and mathematical one.
I: Yeah, I noticed. Did you... did you understand this part OK?
S: I thought I understood it, and then [Aaron] took it another way, and then I didn't understand it, and then he realized he was wrong, and then we went back to my way, and then I was like, "OK, now I understand it again."
I: Wait, what... what... which way is your way?
S: Well, see, I have the same thing written here, I crossed it off, and then I rewrote it.
I: Mmmhmm.
S: Well, this is what I thought it was, and he said no, it's 2000. And I had gotten 7000.
I: Uh huh.
S: And I didn't know how he got 2000. But he... I think he had done all this, and he found out the kinetic energy was 2000, whereas I was doing just this one little part.
I: OK, what I think he did was, uh, took the 70 Newtons up, and he found that the weight is 50 Newtons down...
(Time 14:00)
S: Mmmhmm.
I: so the net force is 20.

S: Mmmhmm.
I: And if you plug that net force in, [yeah] then you get... then you get 2000 right away. But... I mean...
S: That's not what they were asking.
I: The work the engine does on the rocket, right. So... so this calculation is correct, and you got that now.
S: I mean, I was reading the problem here, and I got that, and then he came up with 2000, I didn't know how he got it from just looking at the problem.
I: Mmmhmm.
S: I mean, I understood it when we were done.
I: If kinetic energy equals total work minus potential energy... and total work means what?
S: Well, it's how much force the engine's doing.
I: Oh, the work by the engine?
S: Yeah.
I: The work by... the thing doing the energy supplying?
S: Yeah.
I: OK. Um... right.
S: If we're assuming, like, a closed system, you know, that all the force is gonna be transferred either to kinetic or potential energy, and there's not gonna be any... you know... other projectiles.
I: I mean, all this... all the 700... or... 7000 Joules of work...
S: Right.
I: will go into these things. These two things. [Right] OK. Um...
(Time just after 15:00)
S: But I'm sure that there can be other things that they fall into. You know, if any parts of the rocket breaks off, that's going to be projecting them, or if there's heat involved, that might have something to do with it.
I: OK. Um... (pause) do you think using... I mean, I saw your group debate on whether using 10 instead of 9.8 is the cause for the missing 200.
S: Well, they said it wasn't... much... but it's something, so...
I: OK, it... I mean, is it all the 200?
S: I didn't calculate it... no it's not all of it. They said it wasn't... it wasn't close.
I: Yeah, 200 off of 2000 would be 10%, and the difference between these two isn't that... isn't quite that big.
S: No, that's why I have other things listed as far as air resistance.
I: OK. OK. Um... and those... those are satisfying for now?
(Time after 16:00)
S: Yes.
I: OK. Um... now, I... I didn't see it, was there a lengthy checkout at the end with the instructor? I mean, I'll see it myself later, but...
S: No, I don't think so.
I: Just... did anyone come by, just look at your numbers, and say, "oh, that looks good," and let you go?
S: I think we just left, actually.
I: OK. Maybe there isn't much more for me to watch, then.
S: No, like, we... actually, we spent a while, because it was Andy's birthday, we talked about that, and then we kinda just left.
I: Is it one of the magical ones? Like 21, 22?
S: Yeah, I think he was 21.
I: Hm...
S: What's magical about 22?
I: Nothin.
S: Oh.
laughs
I: It was the least interesting birthday I've ever had. Uh... um... right. OK. So you got through this pretty quickly. Um... what was the, uh... wait... how did the test go for you, I guess?
(Time 17:00)

S: Not well, I just... it wasn't a very good day, I didn't get very much sleep that night, but, um...
I: Because you were studying for... for it late, or...?
S: I was doing homework for another class.
I: OK.
S: That took me longer than I gave myself time for. Well, not, like, that much longer, but I don't know. But, um, on the exam, like... we had to use, like, there was a set of equations that were the acceleration, velocity, position equations you're probably familiar with... that, um...
I: It's like the definition of velocity and acceleration, for example?
S: Well, the ones that involve time and acceleration. Um... let's see (opening bag) these... toward the top.
(pause)
I: You were given these to memorize?
S: No, I memorized them on my own.
I: Oh, you memorized these on your own.
S: They didn't tell us to, but I figured we'd need to, and then we did... and, so, I was glad I memorized them, but I didn't know if I had 'em memorized the right way, because I had a little trouble with the first problem.
(Time after 18:00)
I: So the equations are v equa... wait, v is what? V final? Is that, like, a...
S: V average, v final. I just copied 'em out of the textbook.
I: OK, cause... v equals v-naught plus a t, delta x is one half v-naught plus v t, delta x equals v-naught t plus 1/2 a t squared, v squared equals v-naught squared plus 2 a delta x. So, wait, you're not sure if this is average velocity or final velocity?
(pause)
S: Um... I don't know what the difference is between those. Like, the... v-naught is initial velocity [OK], and v is whatever other velocity I have in the problem.
I: OK. Um... so... you suspect the test didn't go well because you thought you might have memorized these wrong?
S: Well, I was doing the first problem, which was... well, it was, um... throwing something. You had a y direction and an x direction.
(Time after 19:00)
I: Is this the one that Brian graded?
S: Yeah.
I: OK... so you're throwing something... how's it work? At an angle?
S: Shooting something out of a cannon, or throwing something. No, it was a baseball! That's what it was. You're hitting a baseball. [Mmmhmm] So it's gonna go up and then come down, and they wanted us to calculate how far it was going to go.
I: OK.
S: Or no. They gave us how far, they wanted us to go to, like, the end of the field. Hit the wall, whatever. They wanted to know how long it was gonna take to get there, I think.
I: OK.
S: Or the speed, or something like that. But they only gave us the length, I think. I don't think they gave us anything else. They might have given us initial velocity, and... I think the way you're supposed to do that is I had to calculate the time from the... the y direction and use that to find the time in the x direction. Something like that. Cause I was working on a problem with my friend, and that's what we did, but then when I got to the exam, I had forgotten about it, and I was trying to use the equations. And none of them worked, so I thought, "Oh, I must have forgotten something in one of the equations." It would have been much better if he had given us these equations for the exam.
(pause)
(Time well after 20:00)
I: Oh, like, what? Written them on the board?
S: Written them on the board, given us a page [a sheet, mmmhmmm], you know? Allowed us to bring in a card, and write down stuff we wanted to. A lot of... I had a lot of professors that do that.
I: Mmmhmm.
S: We can bring in, like, an index card and write down whatever thing we want on it.
I: So if you had an index card with all the equations on it, you would have gotten it just fine?

S: I would have not... I probably would have... well yeah, I would have gotten a lot better cause I wouldn't have spent all that time trying to remember it, thinking I had it wrong. I would have just known I had the equations right, and worked from that point instead of spending all the time trying to figure out the equations. I mean, part of it's my fault in not memorizing these more solidly, but...
I: OK.
(Time 21:00)
S: I don't know. We never used these in lecture, like, I used them on the homework a couple times, but I always had them written down, I referred to them... and... I don't think he told us to memorize them either. He gave us this one study sheet of what to study for the exam, and I don't think any of these equations were even on there. No. So... these just have very basic things of... what velocity is, what acceleration is [mmmhmm]. These equations are not on the sheet.
I: These equations... these equations come from those.
S: OK.
I: Um...
S: I suppose you could derive them from these.
I: Right. [but] But these...
S: you don't wanna have to do that on an exam.
I: These... these you think are more useful?
S: Well, yeah.
I: OK. In this form. Um... was there anything you remember doing in tutorial that, uh, explicitly helped you out a lot on any of the questions, or... I guess, not?
(Time 22:00)
S: Not really. My help with the exam mostly came from doing the homeworks.
I: Mmmhmm.
S: And, uh, I have a friend Sam who helped me with studying for the exam.
I: Is he the physics major that... wait, are you the one that talked about studying with a physics major?
S: Yeah.
I: OK.
S: He's actually an engineering major, but he's taken physics before.
I: He's taken a year of it here, right?
S: Yeah. It was funny. He's not even in the class, but me and another mutual friend of the two of us was also in physics, so he just was, like, helping the both of us out on our physics stuff.
I: Hm. All right. How... how about the rest of it? I mean...
S: The rest of the exam?
I: Yeah.
S: Um... second problem was something about a ladder falling. I probably screwed that up because it was a free body diagram. And I always feel like I forget things when I write a free body diagram. Just like... I labeled something wrong, and I forgot something. I just have that feeling. And then the third one was an estimation one, and the last one was an essay one. And personally, I don't know why an essay problem is on a science exam.
(Time after 23:00)
I: Do you remember what the question asked?
S: Essay problem was... which of Newton's laws do you find most counterintuitive, I think?
I: Uh huh?
S: And explain why it's not as if you're explaining it to your roommate. Something like that.
I: OK.
S: So... I just picked one at random.
I: Why were you surprised that that's on a science test?
S: Well, I... I guess I wasn't surprised it was on *this* science test, actually, he told us there was gonna be an essay, but I was just annoyed because on a *science* exam, and physics is a science, I don't expect essays on exams. I expect problem solving. I expect, you know, like... I expect essays on a literature exam, on an English exam [mmmhmm], but not on a science exam, because, like... I mean, you... you should be given a whole bunch of problems and solve them. That's a typical science exam. And... I mean, not that essays are, like, bad, it's just, they're really different and if you're going to come at this stage in education as, you know, college students and give them something different, it's...
(Time well after 24:00)

I: I mean, do you think you did OK on that one?
S: I should, unless they got picky about something.
I: OK.
S: Which I know Brian likes to do, looking at my homework.
I: Oh, is... is that not going as well as you hope?
S: He just wants me to justify every answer, and I wish I had the patience to give him about ten pages of homework so he could be...
I: You've told me about this before, I think.
S: Yeah, and... I get... I don't lose that much, I lose, like half a point, but still, it's like... why should I justify something that's painfully obvious when I have all this other homework to do, you know, within physics. I have five problems, and you want me to spend all this time justifying the easy problem [mmmhmm]. I don't know. I just... I'm irritated with a lot in the class, and I take it out on Brian, I suppose. He had us fill out some... a little homework thing of... what we like about his teaching, and what we don't like about his teaching. And I was probably a little harsh, but I actually wrote him a paper. I was like, "I'm sorry if I was harsh." So...
(Time well after 25:00)
I: Oh, he gave you, like, a freewriting kind of thing?
S: Yeah, well, he wanted us... he gave us...
I: Wrote anonymously, kind of?
S: Yeah.
I: Hoping he doesn't... learn anyone's handwriting. Heh. No. All right, that's something I've heard TAs do before, but I... I'm sure not every TA is doing it. It's a suggestion I'm sure he's heard in passing. All right, well, I mean, that's exactly what that's for, so I'm glad you got a chance to vent to him. Cause, you know, venting to me does you no good, cause I don't talk to him about this.
S: Right. I don't know, just... I feel like there's a discontinuity between what is taught in lecture and what is expected us... expected of us on homework and exams. And I think a lot of other students agree with me, cause we talk about it a lot in tutorial.
(Time after 26:00)
I: Well, you said that, actually, doing the homework was the best preparation for exams, though, so how...
S: No, no... not between exams and homework. I mean, between lecture and exams and homework.
I: Oh, between... oh, oh, you think there's a disconnect between lecture and the homework, too?
S: Yeah.
I: What's not being done in lecture?
S: I don't think he's gone over these equations? And...
I: Which ones? Like, the ones that were on that sheet of yours? Like the...
S: The ones I just showed you.
I: Yeah, the... like... the v... you know, the x equals v-naught t plus a half a t squared. [yeah] Stuff like that? Oh.
S: I mean, yes, you can derive them from the simple ones, but [OK] if you give us simple ones, and expect something complicated... why not just teach the complicated?
I: Is that what he's doing, do you think? In lecture?
S: He, well... actually, Brian mentioned it today. That, um, he explains a lot of theory [mmmhmm], he doesn't explain very much problem solving.
I: OK.
(Time 27:00)
S: And Brian said he was gonna start doing an evening session to talk about problem solving.
I: Oh.
S: On, like, Wednesday and Thursday nights.
I: Huh.
S: So... supplemental lectures, I guess.
I: A generous use of time, I guess.
S: Yeah.
I: Did you plan on going?
S: Yeah, I'll probably go at least once to see what it is and [OK] more if it's helpful.
I: All right, I'm glad we had some quick tutorials to go through, cause, those were some pretty

common and valid concerns that I heard from you.
S: About the class?
I: Yeah, class, test, whatever. All of that stuff.
S: Well, I know I'm easily irritated, but we talk about it a lot in tutorial, so I don't think I'm the only one.
I: Yeah, I know... I mean, I've seen...
S: I mean, you've seen the tapes.
I: Your group, and your not the only group, trust me. So... let me stop this.
(end of tape)

Interview 7: Energy conservation

The main topic of this interview was an energy conservation tutorial Patty's group had done. Her group came up with an answer one way, and the TA tried to correct their method. However, the group's answer was correct, and Patty used this opportunity to discuss how getting told to do the problem a certain way was not helpful for the group.

(Time 0:00)
I: ... next to UMich.
S: You didn't apply to that one?
I: No.
(pause)
S: (offering food) Want any? Peanuts?
I: Um... yeah not... not this second, thanks. Um, so, let's see... I have the questions, and you have that. All right.
S: My mess. (?)
I: Um... I guess the first... so, the first questions... this was kind of different in that it was sort of a problem solving thing, I think.
S: Mmmhmm.
I: Um, and so, I mean, that's good, you need to know how to do that. This maybe helps you learn how to use the energy conservation stuff but... you were talking about using, you know, like, two formulas out of three or four that you had on a list somewhere. Does that sound right?
S: Yep.
I: Can you show me or tell me what formulas you're talking about? And, uh...
S: That one there, um...
I: Wait, so...
S: Delta x...
I: Wait, delta x equals v-naught t plus one half a t squared.
(Time just after 1:00)
S: And this one here.
I: And v equals v-naught plus a t.
S: Yes.
I: Right.
S: And it made sense, and I used it, and then... I got the answer, and then Solomon's like, "no, don't do it that way."
I: Solomon said no, don't do it that way. Um... right. Now, were there, were there other equations sort of in your arsenal that you had on the list that you looked and you decided not to use?
S: Um... I didn't really compare, I just, like... my eyes landed on those first, so I used it. And then,

um, we could use that one. v squared equals v-nought squared plus 2 a delta x.
I: Or just use... v... v... v-naught squared plus 2 a delta x. And what would the del... uh, like, for one of these questions, what would the delta x be?
S: It would be the height, the... 3... or the 2.3 meters, and then the point three meters. You have to do each...
(Time 2:00)
I: So, you have to do each step. Because you talked about that, right? So you... you treat from here to here [mmmhmm], um... (pause) as, uh... (pause) one phase of it, and then going up from the floor to point B as another phase?
S: Right.
I: OK, so... right. [And it might have been...] You... you picked these because these are basic equations of velocity, acceleration, motion, stuff like that?
S: Yeah. They have been useful in other problems.
I: OK.
S: That were similar.
I: All right, so... let me just... let me just go over your method, I guess. Um... (pause) so del... delta x is 2.3 meters, so that's just, like, the distance you're falling, right?
S: Right.
I: Starting from rest... one half a, and you just use g [right]. Why did you use g?
(Time 3:00)
S: Cause it's falling. And there wasn't anything else [OK] pushing or pulling on it.
I: So if something was just dropping straight down 2.3 meters, this is how long it would take?
S: Yeah.
I: OK, and... and it doesn't matter that the track's curved? It would take the same time?
S: Yeah, I kind of just ignored that.
I: OK. Um... and then, start from rest...
S: [Aaron] pointed out later that if you're on a ramp, it doesn't matter how long the ramp is, as long as you start from the same height.
I: Uh, what doesn't matter?
S: The angle of the ramp doesn't matter.
I: In determining what? The final speed, or how long it takes to get there?
S: Final speed.
I: OK. So... so the final speed doesn't... doesn't matter, um... (pause)
S: Doesn't matter whether it's on a ramp or whether it's dropped from straight down.
I: Doesn't matter whether it's dropped from straight down. OK, so... so this is... this 6.23 meters per second is...
(Time just after 4:00)
S: That's the...
I: the final speed you get, uh... so it's... and that's for the bottom.
S: No, the... the 6.23 is at B.
I: Oh...
S: The bottom is 6.7.
I: Oh, the bottom is 6.7, sorry. OK, and then you go up, and you have an initial velocity... this is a quadratic equation?
S: Yeah.
I: And you solved it and got this answer?
S: Yes. I just used a calculator to solve it real quick.
I: Mmmhmm.
S: It's not perfect answer, but it's right to within, like, point 003, or 001 or something.
I: OK, so, let's see... so delta x is now point 3, and that equals all of that stuff... and you got the time... the time is 1.32 seconds. And then... and now, and now a is minus 9.8?
(Time just after 5:00)
S: Yeah.
I: OK. Um... and so v equals minus 6.236. All right. And, uh...
S: So it's negative because it's in a different direction.
I: Oh, the... the acceleration is different in these two dire... in these two cases, going from here to...

from A to the bottom, and from the bottom to B?
S: Well, I had to make 'em different in order for my answer to make sense.
I: Oh, you had to make them different for your answer to make sense. OK. Um... now, what was the other method that you used that gave you the same answer? There's v...
S: Over here, on the side.
I: Oh.
S: This is actually the first part here, and that's the second part. The equation we used was mgh with the mass, gravity, height [mmmhmm] equals to one half m v squared.
I: OK, and...
S: That gives you the final velocity for the first part, when it hits the base.
I: Uh, gotcha, OK.
S: That number turned out to be the exact same number we got for the first part in the other problem, (other?) method.
(Time just after 6:00)
I: Yeah.
S: And then we did... to find the second part, when it's going back up, we did one half m v squared, and this v is the same...
I: Is the 6.71 you got?
S: Right, and that equals m g h plus one half m v squared, and this is a different v.
I: And that's a different v, and that's the final answer.
S: Right, that's the final velocity.
I: OK. Um, and the g's are all a positive 9.8 now?
S: Yeah.
I: OK.
S: I guess that's a better way to do it.
I: OK...
S: Although this will give you the exact same answer.
I: 6.25 and 6.2...3. OK. Why do you think there's a difference?
S: Uh, I dunno. Maybe because we didn't use 6.71, and I used 6.7.
I: OK. There's... there was a part when you were doing in section 1 where you mentioned that there was something that you wanted to check, but you couldn't? Do you remember saying something like that?
S: Yeah, I think so.
I: Do you remember what that was?
S: Did we just want to check what the right answer was? Maybe?
(Time 7:00)
I: Um, well, no, I mean, this was before you consulted the TA. It was like you were doing some work, and you wanted to see if your answer was right, but you couldn't check it somehow.
S: Oh. I don't know.
(pause)
I: OK. Um... so, I guess... I mean, I guess that the question is... I mean, to you, these two answers are the same. 6.23 and 6.25.
S: Yeah.
I: Um... I mean, first of all, is it a coincidence that these answers came out the same?
S: It could be, but I didn't think so.
I: OK.
S: Especially cause our initial velocities were also the same. I mean, we got... we got two different numbers, two different methods, and they came out the same. So I figure that was checking enough.
I: OK. Um...
S: But apparently...
I: Did... do these seem like two different ways of approaching the problem, or are they different ways of saying the same thing?
(Time just before 8:00)
S: Um... probably different ways of saying the same thing. (pause) I don't know. You have a lot of the same stuff in here. You've got, I mean, in this... actually, in each of these, your masses would cancel, so you don't even need to know that for these equations. You've got mass on the other side,

your g is equal to your a. Height is equal to delta x, so yeah, it seems like it's just a different way of writing it.
(pause)
I: So heights are equal to delta x, I mean, do the equations look the same?
S: Well, no, they look different. They've got different variables in there, and they're set up differently, but you could probably change it.
I: So, in what way are they saying... I guess that's the thing I don't get. How... how do these things look like they're saying the same thing in different ways to you?
S: Because they're... well, they're using all the same variables. You're using delta x, you're using velocity, you're using acceleration, and you're coming up with a relationship between those three. And that's the same as this equation. You have velocity, acceleration, and, uh... delta x. Yeah, I suppose it's... this one's better for it. Because time's been factored out.
(Time well after 9:00)
I: Oh, right, so... so you like the similarity of these more, um, with, uh... the v squared equals v-naught squared plus 2 a delta x because there's no time in it?
S: Right.
I: And so... OK.
S: Well, yeah, look, that's... almost a perfect example of this one, I think. Because if you cancel out the ms, substitute delta x for all your hs, and a for your g, that's gonna be... and... you know, your ms will be gone. So v squared, your initial, which is... that one.
I: Is two... mmmhmm.
S: And, uh... gonna be, uh... one in front of that, and that's gonna be a two.
(Time just after 10:00)
I: Mmmhmm.
S: Two delta x a, which we see right here.
I: Uh huh.
S: And then, um... that's gonna be v final.
I: Oh, OK, so let's see. The one half m v1 squared equals mgh plus one half m v2 squared, if you cancel the ms and multiply both sides by two, it looks a lot like this other equation you got.
S: Well, it's almost ex... well, except for a negative sign, which I may not be accounting for... you've got three terms here which are the identical three terms you have here.
I: Oh, OK. All right. That's neat. Um... how... so... um... before I move on to question C, I mean, so... what... what effect on your group did the TA intervention have? Basically, he came by, and he saw what you were doing.
S: He said, "That's all wrong."
I: And he said, "you can't do it this way." Um... you know, use conservation of energy, so...
S: Yeah, well...
(Time 11:00)
I: What did that... I mean, how did you take that? Was that... did that hurt the way your group worked, or was it all OK in the end, or...?
S: We thought we had it figured out. Or at least, a method to do it, and he comes over, and basically, "nope, that's wrong." You know, we were kind of like, "OK." You know? And then he's like, "try it this way." I don't know, it was just... it's like... we... we approached this problem with this method, and it seemed to make sense, and he just came over, and he's like, "No, that's wrong." We were just, like, I don't know [mmmhmm]. I guess we were... I wasn't trying to consult it... but... and then we... we followed [Aaron]'s example of this equation he came up with.
I: This... this is the conservation of energy equation?
S: Yeah.
I: OK. Go on, what were you saying?
S: So, then we did that, and then we got the exact same answer, so it was like, what was wrong with the TA that we got the exact same answer? He just wanted us to do it a different way? And, then we were really, like, annoyed and confused.
(Time after 12:00)
(pause)
I: Hm. OK. Um... so, how... how did you approach C? Um... it looks like you just used the v squared equals v-naught squared plus 2 a delta x again?

S: Yep. They seemed to work for me before. I don't know why the TA didn't like them.
I: Mmmhmm
S: But, the... I don't know... it's an equation that's simple to use.
I: Did you know how... I mean, you said you started talking about D, but you didn't get there yet. Um...
S: We didn't know what units Joules was in, so we were trying to figure that out, and we didn't get much further than that.
I: OK... OK, I'll watch that again towards the end, just to see what you tried. Um... would you... would you be able to... do you think you'd be able to use the Joules in this method that you used?
(Time just after 13:00)
S: I don't know.
I: Put them into here somehow?
S: Well, what units is Joules in? We never did...
I: I mean, Joules is a unit of energy.
S: I know, but... is that, um... like, is it mass over acceleration over time, or something... some relatonship between mass, time, and speed, or...?
I: Well, Joules... Joules is energy or work, right? You remember how to get work?
S: That was, uh... yeah, we were looking at the equations from last lab, or, last tutorial. We had, like, force times delta x is equal to work.
I: So, so, right, so, a Newton times a meter is a Joule. OK. Or, uh... a kilogram meter per second times a meter, so kilogram meters squared per second squared [OK] is a Joule, so... for example, m v squared is a kilogram times a meter squared per second squared, so each of these things could be written in Joules.
S: OK.
I: But these couldn't, cause there are no masses in here. I mean, I guess we could put one in, but...
(Time just after 14:00)
S: Well, this equation is the same as this one, upon the addition of mass to each term.
I: Uh huh.
S: Which is the same as multiplying it all by a constant which is... like, algebraically, that doesn't change the equation.
I: All right, so, one other thing I'm going to draw quickly on this and ask about. Um... now, you said... there was the idea in your group that if something, you know, fell straight down, or went down a track, the final speed would be the same in both cases.
S: Mmmhmm.
I: Is the acceleration the same in both cases?
S: No.
I: OK. Uh, so... what was the acceleration for the case on the left where it's just falling?
S: Um, 9.8 meters per second?
I: It's 9.8, and is it greater than that, or less than that?
S: Oh, I suppose it would be less than that.
I: Oh, OK. Um...
S: So that's different than the, uh, final velocity. The final velocity is the same, the accelerations are different.
I: And it... I mean, it just takes more... I mean, takes more time...
(Time just after 15:00)
S: More time and a greater distance.
I: To go this way. Um... I think that was the thing that he was talking to you about when he was looking at the way you did these... these formulas.
S: OK.
I: Um...
S: It would've been helpful if he'd mention it.
I: You're... you're... I mean, you're going from here to here [mmmhmm], you're not falling straight down.
S: Right.
I: Acceleration isn't 9.8, then. Now, you gave me a different piece of reasoning, eventually, I mean, you said using something [Aaron] said, that for determining final velocity, it doesn't matter if you fall

straight down, or if you go down this curved path. Uh, that reasoning may have satified him. I mean, to say, you know... we're treating this like a free fall [mmmhmm], and then finding the final velocity, and it should be the same both... both ways.
S: OK.
I: So...
S: I don't know. I didn't fully understand it, but I got... I used this equation, and...
(Time just after 16:00)
I: Wait, understand what?
S: Well, the equa... the question, what it was asking. Like, I knew what it was asking, but I didn't know how to get it perfectly, so I tried some things, got it wrong, the TA came over, and is like, "that's wrong, do it this way." And we're like, OK, so we tried, got the same answer, and then... like, we didn't learn anything in that.
I: So, I mean, do these conservation of energy equations not make as much sense to you, then?
S: I suppose they make sense, but I don't know why I would have gotten the same answer. Is that just... is that a coincidence?
I: Well, I mean... in... that's what I asked you at the very beginning.
S: Well...
I: Is it a coincidence that they're the same, or...
S: If... if these are... are what we should use, and they're basically the same thing as these, then why are these wrong?
I: You mean, if they give the same answer.
S: OK.
I: Then... wait, I mean, is that... is that what you're asking?
S: Yeah.
I: So if... if these give the same answers, then these... why is that wrong?
(Time just after 17:00)
S: Yeah.
I: OK. Um... I haven't checked through all of your math, but, I mean... at least... at least this first step here, and the reasoning that you use, that, you know whether it goes straight down or a curved path, that's valid. So it's... I mean, that was a valid way of getting... getting this 6.7.
S: OK.
I: I think. Um...
S: Well, it's like, if you say A is equal to B, and A is right, well, then B has gotta be right, but he was saying that, like, my method was wrong.
I: OK. So, I think this is right. One... one thing I'm not entirely sure about, um, here... for the second part of the motion, you have initial... the initial velocity is 6.7.
S: Mmmhmm.
I: Uh, what direction is that?
S: It's... well, I suppose it's kind of horizontal?
(Time 18:00)
I: OK, so... what's the meaning of a negative velocity, then?
S: A different direction? Opposite direction from where the initial velocity was?
I: I'm just wondering, does the fact that that sign came out make sense to you? I mean...
S: Yeah, it made sense, because A was going down and B was going up.
I: Oh, so at... at B it's kind of moving upward?
S: Mmmhmm.
I: OK.
S: That's why the negative wasn't... wasn't something I stumbled on.
I: Is it... at this bottom point, is it moving up or down?
S: I suppose neither, but for the sake of the equation, I was counting it as moving down.
I: You were counting it as moving down. So that's why the 6.7 is positive? And anyway, it gave you an answer that made sense?
S: Yeah.
I: OK. I mean, if... if I were a TA, and I was looking at that, those are the kind of details that I would ask about. Um... OK, and I don't know if he was asking about the same thing, but... um... I think it's.
S: He didn't really ask about specifics. He was just kind of like, "that's the wrong way to do it, do it

this way."
(Time just after 19:00)
I: So, I mean, you... you didn't like... you didn't like it when he did that?
S: No, because I came up with this method, it made me wrong, and it made sense, so I thought it was right, and then he came over and said it was wrong. So we did it his way [mmmhmm], and lo and behold, we got the exact same answer, so we thought "what on earth was wrong with the first way?"
I: What was wrong with the first way, right?
S: If the second way gives you the same answer, you know?
I: OK, um... what... how was... there was some allusions in your group to how there was... talked about in class today.
S: Yeah, he talked about...
I: So, what happened in class today?
S: He did, uh... what do they call it? LID? I don't know what it stands for.
I: ILD.
S: ILD.
I: Interactive lecture demonstration?
S: Yeah.
I: OK.
S: He did one of those where you had two ramps that were... well, I'll draw them for you. We had a steep one, maybe about 45 degrees, and a less steep one, maybe about, like, 36 degrees.
(Time just after 20:00)
I: Same height?
S: Yes, same exact height. Balls dropped from each.
I: Mmmhmm.
S: When they hit the ground, will their initial velocities be equal...
I: Or not?
S: Or not.
I: OK.
S: So, like, intuitively, you'd think the first one is going to be faster.
I: Mmmhmm.
S: Cause you think steeper equals bigger/faster/whatever. And then we learned that the initial velocities are equal, but the accelerations are different, and the times are different.
I: Mmmhmm.
S: So, yes, the first one will get there in less time, but in the end, the initial velocity, or the... I guess, the final velocity is the same.
I: So you're satisfied with how you reconciled your intuition? Um... that way?
S: Yes.
I: OK. So, so... what would you say to someone if I said, "well, I mean, the steeper ramp's gotta be faster!" What would you tell me, if... if, you know, I wasn't taking the class, and you had to explain it?
(Time just after 21:00)
S: I'd say, well, why don't you try it out and see? I don't know, like... yes, it will get there faster.
I: It will get to that speed faster.
S: Yeah.
I: OK.
S: Its acceleration is greater.
I: OK. And, and... that's the intuition you used here? Um... I mean, do you feel you used that... that idea when you were using these equations in part A? Or...
S: No...
I: Did what you were doing in part A seem completely different?
S: It seemed completely different except for the one part where I was thinking, oh, because it's going down a ramp, is this different than dropping it? And then I thought about that, and I was like, oh, well, it's probably the same, because they were the same there.
I: When you were doing this equation, this very first one in part A, um... were you looking at this as if it was... as if you were dropping it, or did this seem like doing the ramp to you?
S: It seemed like doing the ramp.
(Time 22:00)

I: OK.
S: I didn't... I didn't think about the ramp... the ILD ramp initially. I just... it came up, and we were trying to reconcile the difference between dropping it and ramping it.
I: Mmmhmm.
S: But I think we confused initial velocity and acceleration again.
I: All right, let's see. (muttering) What equations did you use? How did you use time? I already got that. Um... (pause) uh, oh, for this question (pause) was the two part approach necessary, or could you just have done a, like, a drop from here to this height?
(pause)
S: Um... I don't know, maybe. It seemed like the two drop was nec... the two... cause the speed was gonna change.
I: What do you mean the speed was gonna change?
(Time 23:00)
S: Well, it's going down, it's going to be increasing.
I: Mmmhmm.
S: And then, it's coming up, it's going to be slowing down. (pause)
I: OK.
S: I don't know, maybe that's... if you had subtracted the height of B from A, that height would have been the exact same of speeding up as it would have been slowing down, so maybe it would have canceled out.
I: Hm. OK. Let's see.
(pause)
I: You said that you could solve part A using forces and accelerations. Um... but you... I mean, you quote the same formulas you used, right? This delta x formula and the v squared formula.
S: Mmmhmm.
I: Does that seem like it's using forces and accelerations to you just because there's As in it?
S: Sure. I suppose I didn't use force.
I: Oh, OK. I mean, would... would forces help, or is that not necessary here?
S: I don't think it's necessary, but... if I did it wrong, then maybe they are necessary.
(Time just after 24:00)
I: Hmm.
S: Well, force equals ma, right? So if I use the a part of the force and the m part of the force ended up all canceling out, so in a way I did use force.
I: This... this first checkout was the one that caused most of the problems between... the TA and your group.
S: Yeah. Cause he wasn't helping us at all. Like, we didn't know... we thought we had a method to do it.
I: Mmmhmm.
S: And we thought it was right, and then we came up with another method, and got the same answer, so it was kind of further proof that our first method was right. He came over, and said it was wrong and to try another way. And we were kind of (noise)... and we really wanted him to explain how to do it, and he didn't do that.
I: OK, and you didn't do the circular stuff.
S: No, we didn't do that.
I: All right, uh... oh... I mean, just for your benefit, I mean, it would be helpful to look at this, because I'm pretty sure there is a lab on it.
(Time just after 25:00)
S: Well, Brian said he was gonna go over that with our group, cause I told him we didn't get to that part.
I: OK. How was he planning on doing this? You're just gonna meet with him?
S: I guess next week?
I: Oh. Some other time? All right, well, I'm gonna... we've gone about a half hour for now, I think we've gone through all the stuff you did.
(end tape)

Interview 8: A torque tutorial

This tutorial, like the momentum tutorial, was designed so the students could come up with the equation on their own easily. To Patty and her group, everything they did was straightforward for this tutorial, and my mention of mathematical subtleties did not shake her opinion (not that it necessarily should have).

(Time 0:00)
I: Um... make sure we're going. I think we're going. OK. So, I have a copy of this, too. Wanna see... let's see... (pause) OK, so, compared to the version I have... I need to get a copy of this. The values of the weights have been changed. On mine, the first one is 10 ounces and 20 ounces. I'll show you. 10 and 20.
S: Mmmhmm.
I: 10 and blank, and then w1 and w2. On here it's 250 and 500, and then they were asked for part B to have the 10 gram weight 20 centimeters to the left of the pivot, and (?) 5 centimeters to the right. Um... just so you know... (S starts to speak) huh?
S: Part B they wanted it to be 150. Like [mmmhmm] 250 there, it's at 10 there, but then he said it was 150.
(Time just after 1:00)
I: Oh, oh, so... there was an instruction he left on the board?
S: Yeah.
I: So, what... what's the 150?
S: That's what it's supposed to be, the size of the weight.
I: That sits on... that sits 20 centimeters to the left, so that's what you were supposed to do. OK. I think the reason, so, this is in ounces here, I think the reason they did it... I mean, you could do the experiments just, you know, by doubling the weight or something, um, but they wanted to give you values that you could actually... you could actually do. Um...
S: Oh yeah, because we had the scale.
I: Well, I mean, the ruler was there before, but it was the same weights, and it wasn't in ounces, so it was kind of confusing, I see why they changed that. Um... ok...
S: Plus, it's better to use metric units anyway.
I: Right, um... so, I guess... I mean, I saw you, you spent some... time, let me preface this first. Um, you spent some time balancing the stick, uh, before putting stuff on it. So, it makes sense. Um... which of these did you actually try?
(Time after 2:00)
S: Um, part A, the 250 and 500.
I: You tried A, and, uh... so you put the 500 at 15? Did it work fine?
S: Yeah.
I: I think it seemed to. Um... did you not do this one?
S: No. We just did the first one.
I: And did you not do that one?
S: No, we didn't do that one.
I: OK. Um...
S: Pretty simple concept to grasp.
I: OK, so... you felt you only needed to do the first one, and you were pretty sure the others would be right?
S: Yep.
I: Why did you want to do the first one?
S: Cause I wanted to play with the scale.
I: OK, um...

S: And, I guess it's a good idea just to make sure... I mean, they were very, very similar, so if one worked, they probably all worked.
I: Oh, so you figured once the first one was right, then the second two would be right?
S: Cause there was nothing... you know, experimentally different about these three.
I: Mmmhmm.
(Time 3:00)
S: Just, like, distances of different weights on a balance.
I: Now, what I wanted to see was what equation you got, because, I mean, I know you got it, but you didn't say what you got. So this is for part 1C. The equation ended up being W1d1 = W2d2. Um... OK. Uh, how'd you come up with that?
S: Looking at the four data points for part A and B.
I: What four... what four data points do you mean?
S: Well, for part A, we had the two weights and the two distances [mmmhmm], and the same for part B. And the relationship between those two is this equation, and it holds true for the second part.
I: Holds true for the second part? OK, and, uh, for part D, you didn't figure out what d2 is?
S: No, I just didn't have a calculator on me.
I: That's right, that's right... but... um, OK, let's see. Was there a consult there? I think... shall we...?
S: I know Brian at one point told us to use the other piece.
(Time just after 4:00)
I: What... what, uh... what other piece?
S: For the scale, when we put the hooks on, it kind of pulled...
I: That was here.
S: Yeah.
I: OK. So, wait, what was the problem with your equipment?
S: Um, the way it was set up is that it had the meterstick, and then a hook, and I put the hooks on the same side of the meterstick, so then it kind of twisted the meterstick, so it wasn't laying flat anymore. I mean, it still worked as far as balance, but it was, I guess, a little more unstable.
I: Oh.
S: It had a little... little piece you could slide on that had a hook so the hooks with the weights could hang straight down with that.
I: OK. Um, I think that was the only thing he checked you out on. I mean, not specifically the equation, but the equation was right anyway.
S: Mmmhmm.
I: Now, um, this second page, uh... you got pretty quickly, you think?
S: Yep.
I: Were these questions just super easy for you?
(Time 5:00)
S: Yeah.
I: For your group? OK.
S: Something that we were all very familiar with.
I: So you... you didn't feel you needed to do this experiment in A2? I mean, all the experiments were optional, so...
S: Right.
I: So you didn't need to do the experiment for A2? All right. Um... (pause) so there's no trouble coming up with a formula at the end?
S: Nope.
I: Right. So, most of the... these were the easiest two. I mean, the last... the last page, I mean, you got pretty well, but most of the questions I had were based on some of the ideas that were here. Um... what's... so, you have this torque thing, and you know how to get it, right? You have torque equals weight times the distance. Um, you had a thought, you were wondering if torque was something like velocity where it was positive... where it could be positive or negative, or was it something like speed which just had a value?
S sneezes
S: 'scuse me.
I: Bless you. Um... what's... what's your take on that now? I mean, what does it seem like? Does it seem like it has to be something that has positive and negative, or is it something with just a

magnitude?
(Time after 6:00)
S: I don't know. Um, according to part D it seems like it was something with just a magnitude when you related it to the first equation.
I: What do you mean when you related it to the first equation?
S: When we wrote the equation in terms of w1d1, w2, and d2.
I: OK, and that's the same equation you had on part 1C from before?
S: Mmmhmm.
I: OK.
S: Although... no, that does make sense. Now that I think about it, your, uh... yeah! This is right. Your torque would have to be negative because your d2 distance would be negative. Or d1. You know, one of those distances would be negative.
I: One of the distances would be negative?
S: Yeah, they're in opposite directions, like, if... well, if you take the balance point, is that... if that's zero...
I: Yeah?
S: One of your distances has to be negative.
(Time 7:00)
I: OK, so if... if, um, (pause) I mean, let's say d1 is negative and d2 is positive, cause d1's to the left.
S: Mmmhmm.
I: OK? Does that mean that the left side of this equation is negative and the other side is positive?
S: Yes.
I: OK. Um... would that... would that give you all the same answers if you were asked to determine where the... where to put one of the weights to make it balance? That kind of thing?
S: Well, you'd still use the same equation, we'd just have to keep that in mind. I don't know, like, um... as far as the definition goes, it seems like it would have to be negative, cause you're going in a different direction, but as far as, like, experimentally it goes, it's probably more useful to keep everything positive.
I: Like, experimentally, what do you mean? To, you know, to find an actual distance?
S: Yeah.
I: I mean, cause you know to balance something on the right, you're not gonna need to put something else on the right, that would make things worse [right], you know it goes to the left, and so this equation's just good for the number. Does that sound... does that sound right?
(Time after 8:00)
S: Yeah, I suppose, it... yeah, this equation just tells you the magnitude, and not the direction.
I: OK.
S: I was trying to relate direction as well as magnitude in using a negative sign.
I: All right, so, I'm gonna just say what this says. I'll have a copy of this too, eventually, but... the original torque for A, w1d1. B, what's written down is negative tau equals w2d2. Um, you still think this equal answer for C is pretty good?
S: Yeah, well, they're gonna have to be equal, I just don't know if they are... opposite or not.
I: Well, equal in what sense?
(pause)
I: I mean, if two numbers are the opposite of one another, then they're not equal.
S: Same magnitude.
I: Same magnitude? OK, um...
S: In the way that positive 4 is equal to negative 4.
I: All right. Um... (flips papers). Oh. One thing I forgot to ask about page 2, um... I think you skipped the checkout here, you just didn't think you needed it?
(Time just after 9:00)
S: No, because it was, like, the same concepts as page 1.
I: Same as page 1? OK. Um... you were... you were gone while the rest of your group, uh, were at the table for a while. I think you were the first one to get up?
S: Yeah.
I: Uh, Solomon came by at the very end, like... I mean, your group had finished, and had... like, 5 or 10 minutes went by, and he came by, asked if you got checked out at the end, and I think someone at

your table said you had. So you... I think your group only got checked out once this whole time. Um... can I just check, I mean, did you... I don't think you did, but did you think at all about the questions at the end here? Um...
S: Well, not... like, we didn't think about em very much, they were just little tack-on questions of what did you learn from this?
I: OK, um... well, I mean, A is a quick question... cause, I mean, basically asking did this... did this equation 3D here agree with equation 1C, and they're obviously the same. Um... do you... I mean, this one does give you the right answer at the end between the weights... making the stick balance. Um... I mean, was... was there a point of doing page 1, then, or not?
(Time well after 10:00)
S: Um, well, sure. Page 1 gave us the... the answer for 1C, like, it gave us that equation. And it was a very easy way to understand that equation.
I: OK, yeah, so... D gives you the same equation.
S: Right, but it's a little bit more complicated because we're introducing a new concept of torque.
I: Oh, so... so page 1 is somehow useful because the way you get to that equation is easier?
S: Yeah.
(pause)
I: OK. Why does it help to have an easy way of getting at the equation first?
S: So you are sure of where your starting point.
(Time 11:00)
I: Uh, wait, starting point for what?
S: Well, this... if this equation is your starting point, you know, like, if you later use this equation to compare it to another equation [mmmhmm], you wanna make sure that your first equation is right. And if the way you get your first equation is simple, your more sure of it than if the way you get your first equation is complex.
I: Oh, so... you know, at the end, you got this equation with w1d1, w2d2, this is the end of your roman numerals II and III. Um, and... am I getting this right? You're more confident in this equation because you got it before using an easier way you're more sure of?
S: Yes.
I: OK. Um... I think that makes sense. Let's see. So, I guess... that's it for the specifics on this. There's just one... I mean, one more thing I kind of wanted to ask about. Um, I mean, this was a pretty easy mathematical thing for you to do, right?
S: Mmmhmm.
(Time 12:00)
I: And all the equations came from intuition, or... I mean, you were able to come up with them using, you know, common sense ideas about balancing and... and torque, the stuff on page 2 you did very quickly. Just, you know, I mean, push 2 is better, push 4 is better than push 3. Um, earlier in the class, you had, uh, a lot more things where we asked... asked you to predict stuff, and, you know, then test those predictions, and... some of the ideas, especially for, like, Newton's laws, Newton 2 and Newton 3, the initial idea was wrong.
S: Mmmhmm.
I: Um, like, you know, you thought when the truck... you might have thought when the truck collides with the car, that the truck exerts more force. Um... but, you know, the last couple of tutorials have been... I mean, you've gone through quickly, and your intuition has been right pretty much every time. Do you think it's because, you know, your group or you personally is getting better at applying common sense to stuff like this, or is it something about this material that's just easier, or what?
(Time just after 13:00)
S: Um, probably more of it's easier. Um, maybe a little bit of we're getting used to how these are set up, but I think a lot of it is because, I mean, the con... the concept of force is confused with acceleration, and in day to day living, you don't really... you're not really aware, like, of where forces are coming from, exactly what they do. But this was something very simple, like, I think everyone has pushed open a door before. And if you've ever balanced anything or been on a seesaw, then you understand, you know, page 1 here.
I: Mmmhmm.
S: So this is something we were a lot more familiar with. And... like, we weren't talking about the concept of force, which was something a little bit confusing.

I: So, I mean, force was a confusing concept... um... once you got around it, this stuff is easy?
S: Yeah, well, as far as, like, intuition conflicting things, force is something that you have to think about, and your first impulses aren't always right. I mean, they usually *are* , but it just... you know, you're thinking about something else. Like acceleration instead of force.
(Time after 14:00)
I: It's really acceleration... more acceleration that the car feels?
S: Right.
I: Right? Not more force?
S: Whereas here, like, you don't really have separate terminology. Like, you're dealing with weights and distances. And... that's pretty much it. And I guess torque, you know, a relationship between weights and distances. But you're not dealing with anything else that might... might confuse weight with something else. You know? You're not... you're not dealing with multiple things.
I: So you're not gonna confuse weight with something else? You're not gonna confuse torque with something else?
S: Right.
I: Um...
S: Like, I suppose you could probably think of something similar to it, but your first instinct is going to be to think of it as it actually is.
(pause)
I: OK, and so... just because the... the right answer happens to correspond more here with what you... will go in thinking?
(Time just after 15:00)
S: Yeah, I think so.
I: Might be better.
S: Just because this is... this is pretty straightforward stuff. I mean, we did the experiment, and you don't really need equations to interpret it. You just see it. Cause it's just, like, plain, right in front of you. So, day to day living, you have seen this, and it's plain right in front of you. You haven't really had to think about, like, what exactly is going on with all the forces here, whereas if you see a car crash, you know, there's lots of stuff going on there, and you don't really know what causes what. You know? You don't know if it's force or acceleration or mass, or...
I: Oh, you mean, you're having a little more trouble coming up with, you know, which physics concept to connect it with?
S: Right.
I: OK.
S: And here, like, it's pretty simple, so, there's only a couple things it could be. So...
(pause)
I: Hm. OK, so, uh... all right, so this went fine. What was the lab this week, actually?
(Time just after 16:00)
S: Uh, roller coaster with a loop.
I: Was it week one where you actually had to... had to, like, predict how high up you had to drop it from, or was it the one where you actually, you know, analyzed the data and...
S: Week one.
I: OK, so you had... you haven't tried out your thing yet?
S: Nope.
I: Did... did your group have a hard time coming up with an equation for that?
S: Yeah, we all kinda did. The whole class did, and then... like...
I: It may seem unrelated to tutorial, but, um... you know, you did the energy one last time, right?
S: Mmmhmm.
I: And the page of the energy one you didn't get to was the thing that tells you how to do... [right] how to do that. How did your... uh, I mean, how did your class decide how to, uh... um... decide on a formula or a way of solving that question? I mean, cause you hadn't gone through it in any detail yet, right? So, all of your groups were sort of struggling with the same thing?
(Time just before 17:00)
S: Yeah, like... our group had actually figured it out, but, like, we didn't really understand it too well, but then, like, later, when we understood it, we were, like, oh yeah, that is what we had. Um... one of the things was cause we wanted to use the equation mgh to find that velocity, where it's right at the

bottom [uh huh]... (?) goes into the loop, but that couldn't work because that's a theoretical, and... we need to find, like, more actual, because, you know, there's going to be acceleration and then friction and you want to find kinetic energy, so there's just, like, a lot of different things that we had to consider.
I: Wait, so... so, I mean, because this was an actual thing and not a theoretical thing, we're... were all of your equations completely useless, then?
S: No, not all of 'em.
I: What were you able to do?
S: Um... um, well, Brian suggested to have a, like, use as many... like, use an equation, but make all those... use an equation in which, like, most of your variables, say, all but one of them will be real world, like, experimentally derived things.
(Time after 18:00)
(pause)
S: Well, I don't know, it's... (pause) I don't know. It was kind of confusing, because there was just a lot of different stuff flying around, and... trying to connect different things, and... I don't know. I wasn't paying too much attention, cause I wasn't feeling well today, which is why I left early, but...
I: Left tutorial early, you mean?
S: Yeah.
I: Yeah, you didn't... you didn't miss anything.
S: I figured we were done, so...
I: Yeah...
S: Um... yeah, so, I think, hopefully I'll understand lab better next week.
I: But you didn't really follow what was going on today?
S: No, cause there were so many equations flying around, I had a headache, and I was just like, "I'll understand this later."
I: All right. I'm curious to know what you did, but, you know, if you weren't really following, then I guess... I mean, no point asking about it now. I've taught the lab before, and I know it's hard. And I know it connects to a part of tutorial which you didn't do, so... I'm wondering how you approached it.
(Time after 19:00)
S: Yeah, well, Brian, um... he... oh, he came over at one point and discussed, like, what we would have discovered in the tutorial, in that... um... if normal force is going to be zero when you experience weightlessness...
I: When it's just at the top about to fall off?
S: Right.
I: Yeah.
S: Cause we were thinking along the lines of the normal force had to be... let's see... well, we're using, like... considering directions a lot, and, [mmmhmm] like, what forces and which direction it's gonna be, cause acceleration is going to be in a different direction, like, every point on the loop.
I: But at the, at the top, you know which... which way the acceleration is, right?
S: Right, it's going to be down.
I: Right.
S: But then the normal force of, like, the ball on the ramp is going to be up. And then the ramp on the ball is going to be down, so I don't know which one of those two... important. (pause) But first we were thinking it had to be, like, greater than the acceleration, so that it wasn't overpowering, like, the...
(Time just after 20:00)
I: Have you done centripetal acceleration in lecture yet?
S: He just started it today.
I: OK.
S: I think.
I: So, v squared over r... [yeah, he wrote that on the board] is... is the magnitude of the acceleration that points towards the center. And m v squared over r is the net force that has to produce that. So, um... if at the top, if there's no normal force, which you said, right? The only force acting on the ball is gravity, so... m g = m v squared over r. And that's how you get what velocity it needs to be going to... to make that work. But, I mean, I'm sure if... the TA came by, that's what he did. Centripetal force isn't a special force, it's just the amount you need to have to make it work, and that's what the tutorial is supposed to get at, but... yeah, if you worked it out with a TA, you'll be fine. Um... I think, uh... yeah,

I guess that's all I wanna know, so...
S: Well, we did discuss that a little bit with our little clicker example, was... is this a new force, or is this just a combination of... you know, current forces?
(Time after 21:00)
I: What... what the centripetal force is?
S: Yeah.
I: How'd you vote?
S: Um, combination of current forces.
I: Combination of current forces? OK. Did he give away the answer in class?
S: He said, um... no, he didn't give it away, I think, cause he was just like, "on average, like, in physics, look for a simple definition with things you already have instead of trying to be..." I think, I guess he gave it away, cause he was gonna, like... don't always think something it's completely different. Use what you got first.
I: So that tells you, what, it's not something new?
S: I interpreted it that way.
I: You interpreted it that way?
S: Yeah.
I: OK, I don't know. All right. Uh, yeah. Wonder what he says about that. I haven't been to one of his lectures since the time I taped ILD, so... not sure how he goes through this lab. Anyway, so... that's yours. Um... and, um, I'm done.
(end tape)

Interview 9: A gravitation tutorial

In one of our gravitation tutorials, students are to reason why astronauts appear weightless in space. Patty seems to think the source of her confusion was a mixup of force and acceleration somehow. The evidence is not overwhelmingly in favor of a language glossing similar to her Newton 3 tutorial, but she had difficulty reconciling some of her difficulties here. The interview ends with a discussion of how her professor discussed one of the homework problems in class.

(Time 0:00)
I: I guess, first of all, just a sort of a group logistics question. You had two new people this time?
S: Um, [Annette] and [Deena] weren't there, so... two people in their group also weren't there, so...
I: So, they combined you and kept you at your table, or so?
S: Yeah.
I: OK, so, you were missing two people, but the other two were from your section?
S: Yeah, they just sat at a different table.
I: Like, which one? One, or...
S: Um, like, if you're standing at our table, the one in the top right quarter... corner.
I: The... the... so, the one in the middle?
S: The one, like, right next to the video camera. The one in that corner where you walk in the door, and you turn right?
I: Oh, oh, that one.
S: Yeah.
I: Oh, the extra table, OK. Um... so they were in your section, they were familiar with the TAs, and

how this [yeah] worked out, OK.
S: They just were also missing two people from their group.
(Time just before 1:00)
I: OK. Um... so, I guess the... the first thing in your first section, 1A... um... (pause) I understand how your group said that there was no gravity, and that's why they would float. Um, and you all agreed on that. There was a comment that was made, I don't know... I don't know... I'm not sure if it was you, I think maybe it was... something about reading the text?
S: Oh, uh... one of the new... Emily, I think was her name...
I: Oh, one of the new people.
S: Down here, we all agreed, cause it was, like, in lecture or reading the text, and she was, like, definitely from reading the text, and not...
I: Oh, so that was a response to the wording of B [yeah], so, let's see, what's... is your wording the same as mine? Oh, no. My sample copy refers specifically to Dr. [PER prof], cause it was from a semester when he taught it. Um... so that says "now we'll lead you through a few gravity calculations, and, it says, in lecture or in reading your text, you will learn about the universal law of gravitation, and you have lecture crossed out. You haven't... you just haven't done it in lecture yet?
(Time 2:00)
S: No, cause we don't learn anything in lecture.
I: I mean... has he... so, whether you think you learn anything or not, has he tried to cover it? I mean, have you seen this formula before?
S: Um... not that I remember. I don't pay too good of attention in lecture, but I don't think... I don't remember ever seeing it.
I: OK, maybe that'll be something for the end, I don't know how much you've actually talked about lecture when we discuss these things, normally, we focus on the tutorial, so...
S: Mmmhmm.
I: So (mumbles away from recorder)
S: I have a pen.
I: Maybe I can remind myself of that. Heh.
(pause)
I: OK. Um... all right. So...
S: Yeah, nobody likes lecture.
(Time before 3:00)
I: That's the impression I got, but I'll... I'll be a little more specific about that in a bit. Um... this 1C question, now... I just wanted to see how you worded it, because it... it sounded like on the tape, there was an idea that [Aaron] gave that you just kind of agreed with, but I wanted to see how you worded it. What's the one or two questions or issues that you think the tutorial should address next? So, force of gravity does not equal zero, yet astronauts still float. F of gravity on earth is not that different from F of gravity on the shuttle, yet that's a big difference felt by the astronaut... so that's... that's the question you think is important? Still, right now?
S: What is... explain... oh, well, just... if the forces of gravity are... they're pretty close together, so...
I: Right, it's, like a [yeah] 20 Newton difference, or so.
S: Yeah, 20 out of almost 500 wasn't significant, so... you know, it was just well, OK, then what's causing it?
I: OK.
S: And then the rest of the tutorial explained that.
I: What's causing what? The floating?
S: Yeah.
I: OK. And you felt the rest of the tutorial addressed this adequately?
(Time just after 4:00)
S: Yes.
I: At this point, this was the most important question you had in your mind right now?
S: Yeah, because we initially thought change in gravity, and then we found, like, no, that's not it. So, what is it?
I: OK. Um... now... most of the stuff you did in parts 2 and 3 you got through pretty quickly.
S: Mmmhmm.
I: Uh, the accelerations are 9.8 for example, um, so the dummy will float in midair. Now, you were

asked in part C here, how do you reconcile A with B in part 2, if the 2 are different? [Mmmhmm] Right? So modify the reasoning, and so on. Um... so what you have written down for C is the exact same thing I heard one of your groupmates say verbally on the tape. That you didn't take into account acceleration.
S: Mmmhmm.
I: Um...
S: The common area... error of confusing force and acceleration.
(Time just after 5:00)
I: OK, so... I did remember to write this down, I have a question about that in a little bit. But it... so, this says you didn't take into account acceleration. So that means that you... what? You just didn't think about the acceleration of the cable and the acceleration of the person and that they're the same?
S: Well, we just... we weren't thinking of acceleration at all.
I: OK, so, the one... the one thing that I'm wondering, and this is part of the reconciling that I think is left out, is that you had this idea that the person would rise to the ceiling once the dummy picked the feet up off the floor.
S: Mmmhmm.
I: What were you all thinking when you said that?
S: I don't know, I guess movies where you see that. (pause) Cartoons.
I: Where you... where you see what, specifically?
S: You see an elevator break its cable, and all... everybody in it smash to the top.
I: Oh they... they go up to the top?
S: Mmmhmm.
I: Huh.
S: I mean, the elevator stops, and they all smash to the bottom. Because it's more of a cartoon thing.
(Time just after 6:00)
I: OK, yeah. I guess... I guess I remember that. So, if it breaks, they go foomp!
S: Yeah.
I: And then when it hits the... hits the ground...
S: Yeah.
I: OK. Uh...
S: Either it hits the ground, or, like, the cable's caught, snagged on something, you know, so it stops. Um...
I: Do you have any idea why... why it might be exaggerated like that? I mean, you found out the... if you just lift your feet, you'll stay hanging, but why would it be... why would someone draw it like that?
S: Comedy? I don't know.
I: OK, um... (pause) I guess I would ask you where that idea comes from other than cartoons, but I guess if that's the first thing that comes to mind...
S: Well, I suppose when you're in an elevator [mmmhmm], and the whole feeling of, like, when it, see... if you're in an elevator, and it goes down [mmmhmm], you feel a little lighter at first.
I: OK.
S: So then they just exaggerate that. I suppose.
(Time just after 7:00)
I: So if you exaggerate that, then instead of feeling lighter, you might actually go up.
S: Mmmhmm.
I: OK. Um...
S: And when you... when you're in an elevator going down, and you stop, you feel a little heavier [uh huh] while you're deaccelerating.
I: So exaggerate that, and...
S: And you crash to the bottom.
I: Crash to the bottom. OK. That's neat. Um... Brian, when you were actually doing the checkout, mentioned free body diagrams, uh... what was I gonna say? He mentioned free body diagrams looking at, for example, if you draw a diagram of the elevator, you draw a diagram of the person, there's a force down that's just the weight, it's just equal to mg, and that's how you know the acceleration is g for, um... for both. Does that make sense?
(pause)
S: I'm not sure what you're asking.

I: Um... one way Brian justified some of the work that you did, sort of independent of you...
S: Mmmhmm?
I: is that if you drew a free body diagram for the... the box and for the person, it would just be a weight down, and that's how you know it's 9.8.
(Time after 8:00)
S: Oh.
I: For the acceleration.
S: For the... for the box and the person as one unit?
I: No, I... I mean, used separately, even.
S: OK.
I: Cause they each have their own weight.
S: OK.
I: Um, now... you came up with 9.8. Did you use that kind of reasoning, or did you use some other kind of reasoning to get that?
S: I suppose I used that reasoning, just... you know...
I: I mean... how would you put it?
S: They're both falling.
I: Uhhuh.
S: And, um, constant acceleration due to gravity cause they're both falling. It would be falling at the same rate.
I: Do you need a diagram to know that?
S: No.
I: OK.
S: I think the... maybe the reason for, like, the rise to the ceiling idea is that, like, inside the elevator it's... I guess that maybe this reasoning comes from, like... the inside of the elevator does not act with the outside of the elevator. That, like, the inside of the elevator has no forces except for what's inside the elevator.
(Time 9:00)
(pause)
S: You know what I'm saying?
I: I don't think so. Inside the elevator?
S: Well, like, I don't know if it would be a vacuum or not, but just like, so that the elevator would be a barrier to gravity as well, and that... zero forces are felt inside the elevator that exist outside the elevator. So, [mmmhmm] like, if you had that, then maybe the person would crash to the ceiling.
I: The forces are different inside the elevator than outside?
S: Right.
I: OK. Um... all right. I think I can move on to the next bit. Did you end up concluding in the end that you'd float in the middle the same way here?
S: Yeah.
I: Does the fact that there's horizontal motion complicate things any?
S: Um... do a little bit, but then, I decided it didn't matter.
I: You decided to neglect the air resistance?
S: Yeah.
(Time just before 10:00)
I: OK. Um... and so you came up with a rule: when the acceleration of the person equals the acceleration of the vehicle... (pause) OK. Uh, is this stuff in parentheses important to your rule? That the acceleration has to be due to gravity and the things have to be in free fall?
S: Yeah. Cause if it was a horizontal acceleration, I mean, you wouldn't be floating as far as, you know, gravity is concerned. Like, I suppose you could design it such that you're floating horizontally, perhaps, but when you're just talking about floating being off the ground, then it has to be vertical.
I: Oh, so there's... there's something special about the direction you want to be floating, like, if you want to float with respect to the ground, then...
S: Yeah.
I: OK. All right. Um... and of course, the two follow the same reasoning, and gravity makes them accelerate, accelerations are the same, and so that works. So... you didn't need to refine your rule at all after talking... so... this section, section 5 didn't help you change your rule at all cause your rule was

already correct?
(Time after 11:00)
S: Yeah.
I: OK, um... so... I guess a couple of things that are left. You mentioned again... and... I like how you brought this up, cause I know you've talked about this before... that acceleration... you didn't take into account acceleration, and that's why the answer at the beginning was kind of wrong, right? If you... if you would have thought of acceleration, um... you could have gotten it right. Uh, do you know, I mean... what a physics concept kind of has to be like for you to get a warning sign that it'll be one of those things that'll be confusing? Like, between acceleration and force, you said?
(Tim gets beaten with a wet noodle for the stupid question)
S: Is there something that I could recognize...
I: Yeah, is there something about that that makes you think, oh, it's gonna be like that, so I have to look at it differently?
(Time just after 12:00)
S: I guess when... when things are equal and you think that they weren't going to be equal for some reason. But, as far as, like, when you first enter the problem, nothing stands out to me that this is one of those acceleration/force things.
I: Is... is it only with acceleration and force? Is that the... is that the only example of something like that that gave you so much trouble this time?
S: Well, so far in these tutorials, I think that's been the main thing that we've confused intuition with physics laws with.
I: Most of the rest of the time, your intuition's right?
S: Yeah, because most of the time we're dealing with... when we're dealing with things that are... we, you know, were familiar with [mmmhmm], then we're fine. But I don't think we are really familiar with what force is, exactly. We just know the effects of force, cause that's all we can... experience.
I: How do you deal with that? What's the way to deal with that, study it, so you don't repeat the mistakes? So you don't get confused if we ask you other questions about it?
(Time just after 13:00)
S: Maybe you could just always have in the back of your mind whenever you put in an answer thinking about acceleration that, oh, maybe it's force. Or, or if you put an... maybe, just, you could always keep in the back of your mind the relationship between force and acceleration, so if you put the answer as one, you could, you know, consider maybe it's the other one.
I: Was there confusion with force here? In this question in part 2 of the tutorial?
(pause)
S: Um... maybe.
I: It just... it doesn't sound to me like you made the mistake here, because you were confusing acceleration with force. That seems to be the... I mean, the acceleration/force confusion is the thing that bothered you a couple weeks ago, or a couple months ago.
S: That was when we had trucks crashing into cars, and...
I: So... so what kind of confusion is going on here, and how is it like that?
S: Mmm.
(pause)
(Time 14:00)
S: Well, I don't know. It's... similar because... we mistook acceleration to be force of gravity. (pause) Relating back to the first page, we thought it was gravity at work here. Gravity's a force. When in actuality, it ended up being acceleration.
I: What... what ended up being acceleration?
S: The reason astronauts float.
I: Oh, because the accelerations are the same?
S: Right.
(pause)
I: Uh, OK. I mean, is there no right way of thinking about it in terms of forces, then?
(pause)
S: I don't know, maybe you could correlate the two. But... initially, you'd think zero gravity, you'd float. Which would probably also work, I guess. Um...
(Time just after 15:00)

I: Right.
S: But as far as why the space shuttle floats... I guess, you know, the floating in outer space is going to be different than floating in orbiting. So... I don't know. I just... I don't see a way to reconcile 'em right now.
I: OK. Yeah, I'm just wondering if there was a specific acceleration/force confusion here, or something else, and I think maybe there was, but just having trouble articulating what the issue is. I mean, maybe you thought the gravity was off when you were in orbit, like, there's no...
S: Yeah, when you think space, you think "no gravity."
I: No gravity, right. That's very common, like, like Brian said, everyone... everyone says that going in. OK. I mean, I think you worked it out just fine, so... I mean, it all worked out in the end, I'm just wondering if this kind of confusion is like the confusion you had a couple weeks ago. I'm interested in that.
(Time just before 16:00)
S: It's similar in that I'm confusing some type of force with gravity, or with... I'm confusing some kind of force with acceleration. It's a different type of force this time, but I'm still confusing it with acceleration.
I: I'm... I'm just trying to draw the parallel, because I think before, tell me if I'm wrong, the... I mean, what you notice in a collision, you see that one car reacts a lot more than the other.
S: Mmmhmm.
I: And it turns out that that's the acceleration you're noticing, and not the force.
S: Yeah.
I: Um... (pause) Here on... on something around the earth, I mean, something in orbit around the earth, there's acceleration, right?
S: Right.
I: There's force too.
S: OK.
I: So... you know... which part of that is getting confused here? [Well, I guess] Or did you think there was just no force?
S: Probably thought there was no force, but... I don't know. I think the similarities is that before we were talking about a horizontal force. Well no, not that, but before, we were talking about effects, and here, we're talking about causes.
(Time just after 17:00)
I: Mmmhmm.
S: Before, we're talking about effects in that we see the effect of increased acceleration. Here, we're talking about causes where the cause for the float is equal acceleration.
I: OK, and you might be confused into thinking the cause is no gravity.
S: Right.
I: Instead. OK. Huh, I never thought of it that way. That's pretty neat. Um... but yeah, that's the end of the typed ones. I think... judging from how much tape has been used, you haven't been at it for that long. I mean, do you care to comment a little bit about what's going on with the lecture? What's up with that? Why people are dissatisfied, do you think?
S: We just don't think he's a good lecturer. Like,
I: What... what does it mean to be a good lecturer?
S: Well, that we can understand the concepts and succeed on homework and exams?
I: Are you not succeeding on homework and exams?
(Time just after 18:00)
S: Well, I think it might have been in lab that Brian was talking about once, that he teaches... the professor teaches a lot of theory based. And of course, the exams are problem solving, so there's a difference there, and... like... I don't know, it's just the way he teaches isn't that helpful for a lot of the students.
I: Were the exam questions like the homework?
S: Yeah.
I: So are... are you just as lost doing the homework?
S: I'm OK doing the homework cause I have friends who are good at physics, and I learn the class from them. I really haven't learned anything from this professor. I've learned...
I: You've learned it from other people while working on the homework.

S: Yeah, I learned it from my friends who helped me on my homework, and I... the tutorials actually are helpful, I do learn... but again, doing tutorials, I'm learning from fellow students. So... I mean, I'm being guided by tutorials and homework assignments, and being taught by other students and the textbook a little bit, but... I don't know, it just...

(Time just after 19:00)

I: Do you take any personal credit for the stuff you're learning?

S: Maybe.

I: It sounds like you were crediting just about everyone else in the class but yourself.

S: Well, I don't know. Maybe when we do the tutorials, like, I have my own input. But, I mean, I probably credit my friends Sam and Matt who've helped me on a lot of my homework.

I: Are they in the class? Are they...

S: No, they've taken it before, they're... they took 171 or something.

I: Oh, physics majors?

S: Yeah.

I: Yeah, I think I mentioned you... I remember you mentioning

S: Sam's an electrical engineering major, and Matt's a physics major, and they're good friends of mine who I can be like, "Hey, help me with my homework," and they'll help me.

I: So what... what's not happening in lecture that's not...

S: He just, like... I think part of it, like... one of the things that I noticed is just kind of annoying is he talks very, very slow.

I: OK.

(Time just before 20:00)

S: And, that's... part of it's comical, part of it's annoying, cause, like... I don't know... just... like, well, he gave an example today of... we're talking about torsion and... cause it's in, like forces being equal together, like, if forces are equal, things won't move... or something like that... as far as, like, torsion... torsion in one direction's equal to torsion in the other direction.

I: Torques, maybe?

S: Torques, yeah. [OK] Torques. Whatever. But like, he gave an example of we had a meter stick [mmmhmm] balance on, uh, a pivot, and...

I: That one in the middle?

S: It was such that, um, three quarters were on one side, and one quarter was on the other side [yeah], and on the smaller side, there was a 1 kilogram weight.

I: So how... how much does the ruler weigh? Was that the question? [*coughs*] OK. Yeah, I've seen other professors give it before.

S: Mmmhmm.

I: So, what happened?

S: A B, C D.

I: Oh, it was a clicker question?

[S *coughs*]

(Time just before 21:00)

S: Excuse me, I can't stop coughing. *coughs* But it was... yeah. So how much does the ruler weigh? And then, um, I figured it out, like... you know, we're encouraged to, like, talk together, so I thought it was... it was a one meter stick, and a one kilogram weight, so a quarter of it on this side, and three quarters on that side. I thought at first, like, it was, um... 1 kilogram, I think. *cough* And I... I had a reason for that, but I didn't really think it through, I just kinda thought really quickly. And then a friend of mine was like, "no no no, it's four because of this." And I was like, "Oh, OK." Cause I had, like, when I first thought of it, I didn't take into account the distances. I just didn't count the weights, and I was like, "Oh, OK, you're right. It's four." But then I, like, sat and figured it out, and like, mathematically, I got it to equal one. Counting on, like, center of gravity of each section...

I: You found what the center of gravity of each part was?

S: Yeah, like, the distance to the center of gravity.

I: For... for both sides of the ruler?

S: Well, yeah.

(Time 22:00)

I: OK, so... so, you took the stuff on the right, and said, you know, it was about an eighth of a meter to the center, and then three-eighths... is that all sounding familiar?

S: I did it... it's still here (getting her notebook?) but I did, um... OK, the 1 kilogram [mmmhmm] and this, it's... um... the 1 kilogram was one unit away from the... or, I guess it was, well, yeah, I just kind of did in, like, one unit, because it didn't matter, they were all the same.
I: Uh huh.
S: So, like, one kilogram was one unit away, and then the center of mass for the quarter of it was .5 units away.
I: Uh huh.
S: And x is how much it weighs.
I: X is how much, what, one section weighs? Or the whole thing?
S: Yeah, one section.
I: One section, OK, so...
S: So, yeah.
I: So then... .5 x plus 1.5 x...
S: So this on one side of the... this is on the smaller side. That's how much weight's gonna be on...
I: And you solved it, and you got x equals one quarter?
S: Yeah.
I: OK.
S: So there was four sections, and 4x equals 1.
I: So that means 1. OK.
(Time 23:00)
S: Right, which is what I originally had, and then...
I: So, so that... that's totally correct, so what was the point of the story?
S: OK, well the point of the story is I did that in about two seconds.
I: Yes.
S: And then the professor began to explain the problem, and it took him 10 minutes to explain that. Whereas I figured it out in a number of seconds. Although he's explaining it, so you expect a few minutes, but it took him, you know... ten... I don't know. It took him a long time, [mmmhmm] and the reason it took him a long time is just cause he talks incredibly slow [mmmhmm], and... I don't know, it just like... things like that that are just annoying. Like, I find them annoying. He just talks so slow. But, um... I don't know, it just... it might be a communication problem.
I: Go on.
S: That, um... a lot of time, people will ask him questions, and he doesn't really understand what they're asking.
I: Mmmhmm.
S: Or... you...
I: No, I mean, if you have more to say, I was just gonna redraw the thing, but... was that it?
S: You want me to draw it?
I: No, I'm just drawing it.
S: OK. Yeah, well, it just... I don't know, I think he said at one point that he had... at least, in the tutorial today, I think Emily said that he hadn't taught the class since before we were born, or something like that. So maybe he's just out of practice.
(Time after 24:00)
I: I... I did hear that in the tape, right. But, I'm not gonna get video of... I mean, I would never take video of... of people talking about a professor, and using it, I'm just wondering. What... what what... you think could be improved? I mean, just if he spoke faster, that would help?
S: Well, I don't know, that's...
I: I'm not gonna tell him this, either. I'm...
S: The whole, just, speaking slow thing. I just think, like... I'm always thinking, "man, like, you could cover so much more material if you just talked faster."
I: Right.
S: Literally, if he talked at the pace... if he talked faster, I think he could cover twice as much material in one lecture. But, um...
I: It is a balance, because so many professors go too fast.
(Time before 25:00)
S: True, true. It is a balance, but... and... that's something that's kind of not that important, but just another thing that adds to it. But, I think the main thing is just, like, when he explains things, he has

his own way of explaining things, and then, like, the homework... it's like, it's different. Like, I don't know exactly how to explain it, but... it's just... he teaches, well, the TA was saying he teaches theory based, and we are required to (switch back?) problem solving based, you know?
I: So, you don't do problems in class? And so doing homework-style problems in lecture might help?
S: Yeah, that might help.
I: OK.
S: But like, like, real life situations [mmmhmm] and problems, like, we do sometimes, but... like, I don't know, we were talking about torques, I guess, today and he was kind of like, you spin it one way, it's this way, if you spin the another way, it's this way... or something. And... maybe he just... needs to give more examples, or something like that. And show, like... for example, if you had this, this, and this, this is the way you would figure it out.
(Time just after 26:00)
I: Mmmhmm. OK. There's actually... I don't know if he explained it this way, but there's a quicker way to do the... this... this problem. Right? On... on this side, I have just the rock. 1 kilogram times a quarter of a meter. And instead of looking at the left side of the ruler and the right side of the ruler?
S: Mmmhmm.
I: I look at the whole thing, call it all M.
S: Mmmhmm.
I: And it's located here, at... its center of mass, and that's also a quarter away, so... that... that gives you the same thing. I mean, if instead of treating the ruler as [oh yeah] two parts, you treat it as just one, um.
S: That works too.
I: Did he not do it like that? Did he do just sort of a slow version of the correct calculation that you did?
S: I think he did it the way I did it.
I: OK.
S: Might have... did he do it? No, I think he did it the way I did.
I: Nothing that quick? OK.
(S mumbles)
I: Uh, you're taking 122?
S: Yeah.
(Time just before 27:00)
I: All right. I... I won't be repeating all of this for 122, uh, with the tutorials and the weekly thing. I have to stop taking data eventually.
S: Well, I won't be having Professor [her prof].
I: That was gonna be my next question, you're gonna... you're gonna take it with [a different prof]?
S: Whoever else is available.
I: OK. All right, well, I'm gonna stop.
(end tape)

Interview 10: Pressure tutorial

After almost a full semester of tutorials, Patty here expresses frustration that there are still times when the TA prompts with a "what do YOU think?" sort of question when the group is confused.

(Time 0:00)
(pause)
I: OK. (pause) So, we're at the pressure tutorial. OK. Um... I guess, first think I want to know is, um... I mean, you've been going to lecture all the time lately, right?

S: Pretty much.
I: Well, most of the time, at least, enough to know where you are.
S: Yeah.
I: OK, I don't need to know specifics. Um... was pressure talked about in class yet, or... or is this your first time talking about it at all in this course?
S: Oh, he talked about... let's see, today he just kind of did a summary of what he did in the past. We had, um...
I: Do you know why he did that? OK. Go on, what were you saying?
S: I don't remember him talking about pressure.
(pause)
(Time 1:00)
I: Nothing at all?
S: Well, I don't pay too much attention in lecture, because it's really boring for me.
I: OK.
S: I just go because I have tutorial right afterwards.
I: Right, um... this, uh... there's an equation, uh...
S: It's on this page.
I: Right. P equals P-zero plus rho g h, you had not seen that in class before? That was completely new?
S: Yep.
I: OK. And... um... pressure equals force over area, that's something else that he hadn't done? At least to your knowledge?
S: That's new to me.
I: New to you? OK, um... now, there was something mentioned that... Brian mentioned that. He said he was not going to test on this. Is that true?
S: I don't know, like, I don't know what he's gonna test on, because he doesn't really tell us when tests are, and he doesn't tell us what they're going to be about, he just says they're gonna be similar to homework.
I: So...
S: So we haven't had any homework on this stuff.
I: You haven't had any homework on this stuff. Do you know... you don't know when your next test will be?
(Time just after 2:00)
S: Well, I just recently found out that it's gonna be, like, Wednesday after Thanksgiving.
I: Wednesday after Thanksgiving, so...
S: But he didn't tell us that in advance. Like, all other professors that I had will give you a syllabus in the beginning of the semester telling you the date of the exams.
I: For all the exams, at the beginning?
S: Yeah.
I: And he... and you just learned this now [yeah] when the date would be? OK. Um... so... let's see. Uh, (pause) just starting on this actual tutorial now. I'm glad I watched, you know, the first couple minutes and didn't jump to conclusions and write a question, I thought... one of you actually thought the water might come out the top. OK. So you knew it would come out the holes. Um... now, your group mentioned that, you know, the... the water sort of streams out like this, right? Um... and as the water level gets to the hole, once you run out of water above the hole, it starts dribbling or it stops spewing out. Let's say the cup in this picture is completely full, and there's enough so that there's water coming out all three. Is this what it looks like?
(Time well after 3:00)
S: Um, actually, I think the top hole... goes down quicker.
I: Uh huh.
S: And the bottom hole squirts out farther.
I: The bottom hole squirts out further, so... so.... like, the paths might cross if the three holes were in a line? OK. Um... did that seem like an important difference to you when you were describing how this works?
S: Yeah.
I: OK, why... why was that... why is it necessary to notice that?

S: Um... well, if one's coming out at a greater pace, then there's gonna be more force for it. It's gonna mean something.
(Time 4:00)
I: OK. Um... now, you had told me at the beginning that you hadn't had physics before this, is that right?
S: That's right.
I: OK, so... do you remember... maybe it's even the same now, I mean... how would you describe pressure to someone? What's your idea of the concept?
S: It's like... something is pushing on something else.
I: So it's a force?
S: Yeah.
I: OK. That seems consistent with the way your group talked about it. Like, like pressure is a force, right? You can include it on a free body diagram, let's say.
S: OK.
I: No, I'm asking you, can you?
S: I don't know, maybe. Sure, I think I did.
I: Did you?
S: Yeah.
I: So, oh... you just... OK, on your diagrams, you just have layer 1, layer 2, layer 3.
S: Well it's... it's kind of the same thing as weight, like... when we talked about boxes sitting on top of each other [yeah?] the one on top is doing a force to the one beneath it.
I: Yeah.
S: That force could be described as pressure.
(Time just after 5:00)
I: As causing a pressure, as the same thing as pressure, or... do you not understand the question I'm asking?
S: Um... I don't know if the word "pressure" is a different type of force, or if it's just... a characterization of the same force.
I: OK, now... um... there was a point D here where it said pressure is supposed to be a force per unit area [mmmhmm] or is supposed to be the size of force per unit area. Um... so the question is what force and what area, and I think your group had trouble addressing that question all throughout the tutorial, even all throughout the checkouts.
S: Yep.
I: So can... wait, can you kind of just describe what went on there? I mean... what...
S: Well, we didn't know if the area was (?) to the... or what it was referring to at all. So we thought maybe it's like the surface... the surface area of the water, but we thought the volume was important in that, um... and then Solomon and Brian were saying it's the size of the hole area. So I guess thinking about it now, the area it's talking about is the size of the hole and the force has to do with the volume of water on top of it.
(Time well after 6:00)
I: What do you mean the force has to do with the volume of water on top of it?
S: Well, the more water you have on top of it, that's gonna make it change.
I: OK. Um... what was I gonna say? When you were working on this, you said you felt that something was unfinished? Uh... with this answer right here? Yeah. As if the question was vague, or you didn't know if you had complete... I mean, you talked about force down, you talked about surface areas on the top of the water.
S: Mmmhmm.
I: Um... (pause) I mean, what other... what clearer question could have been asked there?
(pause)
S: I don't know, like, a lot of the other tutorials we've had [mmmhmm] we've been... we do, like, all the intuition and common sense stuff, and then we go... and through that we derive the equation.
(Time after 7:00)
I: Mmmhmm.
S: And this one, like, we did common sense stuff, but it was really vague, and we didn't really know what it was talking about, and then it gave us the equation. So... that was a lot different than the other ones we've done.

I: Did you not like that as much?
S: No, I liked it better when we derived an equation ourselves.
I: When you come up with the equation on your own?
S: Yeah.
I: OK. Um... there's something else. Oh. You were talking about just now how... you know, your idea was that, you know, like... the surface area of the circle right here, say, between layer 1 and layer 2 is the thing that's important.
S: Yeah.
I: But you said when the TAs came by, they said it was, in fact, the area of the circle on the size... or on the side, rather. They were mentioning something like what happens instead if a pin... instead of a pinprick, if you had something bigger?
(Time just after 8:00)
S: Yeah.
I: Right? Um... now, right here (pause) uh, in question C... in part C here, it says "say you wanna know the pressure at the bottom of layer 2? So what force would you associate with that pressure, and what area?" Now, I understand that, you know, you might not understand what the question means, and this still may be vague to you at this point. But it says that there may be multiple correct answers. So, I mean, you said that... you said that, uh... you know, it might be the surface on top that matters.
S: OK.
I: For pressure. And the TAs both said it was something about the hole. Could both be correct, or are you convinced now that your first answer is completely wrong, or what?
S: I'm pretty sure it was wrong, cause, like, I thought about it. If you had, like, a really big beaker, and then a really little beaker, so that surface area is gonna be larger and smaller [mmmhmm], you put a hole of equal size on each one at the same height, and stuff like that... then it'd probably come out at the same speed.
(Time after 9:00)
I: It would come out at the same speed for the same height.
S: Same size hole.
I: Um... for the same size hole.
S: Mmmhmm.
I: And, how does that disagree with what you were saying about the... about top?
S: Well, if the surface area of the top mattered, then it wouldn't be the same speed.
I: Oh.
S: And then when he was saying the size of the hole, I just didn't consider that before, and I was like, "oh, that would make a lot more sense" because obviously, a bigger hole is gonna have slower water coming out of it.
I: OK... so... so, I mean, have you... have you figured out, I mean, do you think there's anything right in that idea at all? Your idea about the size of the top of the water?
S: Help you find the volume of water. I think the volume's important for the force, but I don't think it has to do with...
I: Didn't you say that there were... that the water would come out the same in both cases?
(Time just after 10:00)
S: Yeah.
I: But there's more volume in the big one, right?
S: Well, I guess you'd have to have the height so the volume was the right... so you get the same amount of volume above it. I don't know, like...
I: OK.
S: Tutorial was not answering those questions for me.
I: OK. I'll... I'll draw between B and C on page two examples of the beakers that we're talking about. So say they're the same height, but one of them is just super wide, right?
S: Mmmhmm.
I: And they're full up to here. And the hole is in the middle like this. Right? So there might be two layers... all right.
S: OK.
I: Just dealing with your idea. Um... now, with... with your idea, which of these has the bigger sort of surface area on top?

S: Well, this one.
I: This one? OK, and... so, let's say we were going to use it, like, the force you might use in your idea was, uh, the force you could associate with the pressure is the gravity or rather the weight of the water above it, right? And there's more weight here, right? So if there's more weight and more area, here's less and less area... the ratio between these two is the same. Um...
(Time well after 11:00)
S: Oh, it's a weight per area thing?
I: Pressure is supposed to be force per area.
S: OK.
I: OK? So... at the same depth... I mean, this is the way the equation works, too. The h in these two cases is the same.
S: OK.
I: So, is there something... you think there's something correct now in what you were thinking? About how maybe... maybe the area on top could be the area associated with a certain pressure?
S: Yeah, I guess so.
I: OK. Um...
(pause)
I: So, even though there's more volume, the two cases might, if you poked a hole, look the same? It would squirt out the same way?
(Time just after 12:00)
S: Yeah, I think so.
I: OK. Um... so... that's part, I think that's part of what this wanted to get at. It turns out, I mean, did you understand, actually, what they were talking about with the holes in the side? How the area of the little hole in the side matters?
S: I understood when Brian was talking about it.
I: With the dime sized hole compared to the pin sized hole? OK.
S: But I didn't get that from this tutorial at all.
I: When we were talking about your idea with the... the surfaces, I mean, we... talked about it as though the weight of the water above it is what matters.
S: OK.
I: Um... is that the same force you'd think about when thinking about the hole in the side? You think? Or...
S: The force that the water's coming out? Is that gonna be the same force that's from the weight?
I: Well, pressure is a ratio of force over area.
S: OK.
I: So, we're talking about different areas now, we're not talking about, like, the area on the top of the water, we're talking about the area of the little...
(Time after 13:00)
S: OK.
I: So, is the force still the weight, or is it something else? Do you have no idea?
S: I have no idea.
I: OK. So I... I mean, I don't mean to... beat you over the head with these questions if you don't get... if you don't understand what they were trying to ask, I can see that, but, I mean, one thing I wanted you to know is your idea about the surface areas on the top was not wrong, you were just given another one, and...
S: OK.
I: So, um... (pause) the comment was made with you and [Aaron] also that question C is open ended?
S: Yeah.
I: So, what does that mean?
S: Vague, like, multiple answers depending on how you interpret it.
I: Um... well, I mean, it said here in question 2... C2... that there are three correct answers. I mean, do you not like questions like that?
(Time just after 14:00)
S: No, questions like that are OK. It's questions like... "what force could you associate with that pressure?" It's like, well, what pressure? I mean, you can associate, like, any... you can associate anything with anything, you know? [mmmhmm] Given the right circumstances. So... we just didn't

know what they were asking.
I: OK, um... (pause) could... could have calling the TA over at that time have helped or not?
S: Maybe, but we were so confused from the start, we didn't really know what to ask.
I: OK. Um...
S: I think because maybe, like, we're dealing with... like, force pushing things down and force pushing things down... and pressure pushing things down and pressure pushing things out, we just got mixed up... what we were talking about when and how they're related, and vertical versus horizontal. There just seemed to be, like, so much stuff going on we didn't know... we didn't know what it was referring to when it asked questions, and we didn't know how they related.
(Time after 15:00)
I: OK. Um... I mean, it's... especially with a tutorial that didn't go well for the group, I mean, I could spend time like this talking for a while, just, you know, fixing some of what went on, and... I don't mean to do that, but I could... I could try to tell you at least what we were going for here at the very end. If there's time left, I'll do that quickly... if you think that would help. Um...
S: Maybe.
I: Let's see... what else? If you wanted... which force and which area? So that was another vague question to you probably. Um... air pressure on the surface... free body diagrams... you figure... OK. So, for F, you figured out that h equals zero refers to the top and not the bottom?
S: Yeah.
I: How did you do that?
S: Because there would be more pressure at the bottom, so if h is gonna equal zero at the bottom, then that would mean less pressure at the bottom.
(Time 16:00)
I: Right, and... and adding h as you go up wouldn't make it do what you want, right?
S: Right.
I: OK, so that was... that was good. Um... so, what did you think about this... about this, this exchange between the two people? You said something like, uh, the pressure is the weight but it isn't always the weight? (pause) Right, so that's one thing I heard. Um... (pause)
S: Well, I don't know.
I: What do you think about this argument? [It's...] I mean, as you understand pressure now. Sorry.
S: It's the weight of the water, but it also could... like... you could define pressure as, like, me pushing on something. And I don't know if that's weight or not, but that's...
I: So, you're exerting some kind of pressure when you push down on something?
S: Mmmhmm. Oh, and, like, if you push, like, horizontally on something, like, you're doing something of a pressure, but it's not the weight, then. (pause) But in a case when you're not pushing, then I guess the pressure would be the weight.
(Time just after 17:00)
(pause)
I: Wait, so it's at least caused by the weight of the water above a certain point.
S: Sure.
I: But, OK, you still might think pressure and force are the same thing?
S: OK.
I: No, am I right, you still have that picture in your head? That, you know, pressure is just like a force pushing down on something [yeah] or sideways, even, if you like? OK. Um... all right. So... did you understand what Brian... (muttered: don't know I actually said that?) do you understand what, uh, Brian was trying to do when he was talking about T and U?
S: I didn't know what he was talking about. Like... see, like, T would have greater pressure, cause there's more water on top of it, but...
I: OK, it seemed that way, right.
S: Yeah.
I: OK, and so... this... this bit of water between T and U isn't moving, right?
(Time just after 18:00)
S: It's not?
I: Well, I mean, would it be moving?
S: It could be. We were not told that.
I: Do you think it's moving? I mean, this little thing of water, does it look like it's swirling around

inside, usually?
S: No, but even in a liquid that's not moving, individual molecules are moving. I don't know.
I: That's true.
S: I'm saying... I guess it would be still to look at. The water would be still.
I: OK, so...
S: As far as relating that to ice, it's going to be moving.
I: What do you mean, relating that to ice?
S: Well, the individual...
I: Oh, the molecules [right] are moving more compared to ice, where they're solid. Right. Ice, they're kind of locked in the crystal structure, if you want. Right. OK, um... so, he... he came by and tried to talk to you about this, but that interaction didn't help at all?
S: I didn't know what he was talking about.
(Time 19:00)
I: Yeah, so... can you think of, you know, what kind of interaction with the TA you think would have been more useful for you to help for you to understand parts of this tutorial? I mean, what could they have done that would have helped you more, you think?
S: Told us what pressure was from the get go? Maybe? I don't know, like, I still don't understand it, so I don't know how to teach it.
I: OK, um... so (pause) right. So, a lot of these questions I had... you addressed right away, and... so (pause) so, you weren't ex... you weren't told at first what pressure explicitly was?
S: No.
I: And so... um... the interactions with the TAs weren't that helpful, and wouldn't have been helpful if we included checkouts.
S: Well, maybe they would have been, cause maybe they would have been... like, earlier on, I would have seen, like, "Oh! You don't know what pressure is. That's your problem." Instead of the whole thing, and we're like, "We don't even know what our problem is."
(Time after 20:00)
I: OK.
S: I don't know. In general, checkout with the TAs are useless, but this was a tutorial that we didn't know anything about [mmmhmm], so then more checkouts would've been better.
I: Now, um... like, when you were doing the oomph and the torque tutorials, right, you figured out those equations very quickly by yourself.
S: Yeah.
I: Did you not know... I mean, did you know about oomph and torque before you did those?
S: No.
I: So how... how are those different than... than pressure.
S: Well, I think the thing that it was a liquid, and everything's moving around, and we hadn't worked with liquids before was really different. So we were doing two new concepts in one tutorial: pressure and liquid. So...
I: Oh, pressure and liquid are two different things, and now that there's two instead of one, that... that makes it worse?
(Time just before 21:00)
S: Well, not so much that there's two instead of one, but two when we didn't know either of them. So, like, before, it was one thing that we didn't know, but then it was easy to grasp, and here it was two things that we didn't know and we both found them hard to grasp. Or... found both of them hard to grasp. I just, I think because we didn't know it, like, the whole, like... when you ask a TA, they say "what do you think?" Well, that works out really well when you know what to think, but when you don't know what to think, you're like, "I don't know. Tell me."
I: So, so the answers to these questions weren't as obvious as the ones before.
S: Right.
I: OK.
S: And maybe that was due because...
I: Go on.
S: Oh, well, mabye it's because the questions seemed more vague, maybe it was because we didn't know as much about the topic as other topics, maybe cause less intuitive.
I: Mmmhmm.

S: I don't know, any number of reasons, but we just have a much harder time with this one than the previous ones.
(Time before 22:00)
I: OK, so... I think I... I think I get sort of what went wrong here for the group. I mean, how... how you approached the questions, how you treated the questions. And it makes sense that given all of that, you know, the individual TA interactions didn't work out that well. Um... right. So... so... I'm gonna try to clarify some of the stuff that was said here, and... and I'm doing this only cause I have a question I want to ask at the end of it that might be related. So... [OK] this... this layer thing, 1, 2, and 3... OK? Um... so, the formal definition of a pressure is that it's a force over an area.
S: OK.
I: And, so... it's not the same thing as a force, but it's related to a force. So, at the bottom of layer 1, if you see layer 1... layer 1, like you said, it has its own weight, and it has the force of 2 on 1, right?
(Time just after 23:00)
S: Which part are you talking about?
I: This is layer 1.
S: OK.
I: So if I'm looking just at 1, it has its own weight, and it has a force of 2 on 1, and the sides kind of push in on it, too. All right? So... and, likewise, layer 2 has its weight, it has the force of 1 on 2, and those two are the same cause of Newton's third, right? And it has a bigger force that's 3 on 2. Right? So... its own weight, and, right... And so this force is bigger than these two because it has to balance those two out. And it has... force on the side, as well.
S: Which force is bigger than what? That one's bigger?
I: N 3 on 2 is bigger than either of these, cause these two put together equals that. Cause the water in layer 2 isn't going up or down.
S: OK.
(Time just before 24:00)
I: OK, so... there are these... the forces on the sides... notice I'm not calling them pressures yet, right? So, there's... there are these forces on the side from the container, and there are these up and down forces, right? So on the layer between 1 and 2, (pause) there are a bunch of water forces acting. There's the force of 1 on 2, there's the force of 2 on 1, and at... at this layer... I mean, the water also wants to get out, right? It wants to escape. So this is... this is, um, this is water on sides. (pause) OK. And, for the water on sides, if you have a wall here, here's a little bit of water on the sides, right? There's forces down, and forces up, and there's a force from that water, right, wanting to push it out. But there's a wall holding it in. So if you remove a little bit of this, then that force is gone, and this force has the freedom to push out.
(Time just after 25:00)
S: OK.
I: Right? So, when we're talking about, like, the pressure at the layer between 1 and 2... what's the force and what's the area? I mean, it's asked vaguely because there are a lot of ways to answer it. There's... right, so, there's the force of layer 1 on later 2... and there's the area... I mean, what area does 1 interact with 2?
(pause)
S: Well, it interacts with the area of the whole thing.
I: The whole... I mean, that was your original idea, right?
S: Yeah.
I: So that force and that area could give you a pressure. So...
S: Pressure of 1 on 2.
I: The pressure at this boundary. Yeah, between 1 and 2. Um... since the force of 2 on 1 is the same as the force of 1 on 2, that could... that could be used as your F as well, with the same area. The one that you thought of.
S: OK.
(Time just before 26:00)
I: The... the other set... is this force on this little area.
S: OK.
I: And because they're all at the same depth, all those ratios are the same. So... I mean, this sideways force is not the same as this down force and this up force.

S: OK.
I: It's something else. It's just whatever it is that causes the water to squirt out. But the area is different, too.
S: And the ratios are the same?
I: The r... at the same depth, they are.
S: OK. You're saying the horizontal force pushing it out divided by the area of that hole...
I: Yeah.
S: That ratio is the same as [as] the force pushing down divided by the large... sorry... large area.
I: Yeah, 1 on 2, over the large area.
S: OK.
I: Right. At a given depth. So... so all these forces on the diagram... that's why I think Solomon had this obsession with saying eight forces, rank them, and so on and so on. They're not all the same. But some of em, if you combine em... if you think about combining em with the right area, and you had the right idea, at least in one way...
(Time after 27:00)
S: OK.
I: You can get the same pressure. Now... I mean, does that make any more sense than...
S: Yeah, that makes more sense.
I: OK. So... there was something going on, I think, where... I mean, you told me yourself, you consider pressure like force, right? You... you press on something, you exert a force on something, that's like you're exerting pressure on it, right? There's water pressure if you go underwater, the... I mean, the water presses on your ears, there's a force.
S: Right.
I: But force and pressure aren't the same thing.
S: OK.
I: So... this is a... this might be an example of a concept where... you know, there are... there are two physics terms, right? One of them, pressure, which you have an idea what it is, is not the same as the physics definition.
S: OK.
I: How would you... you know, reconcile these concepts, work them out so you don't get confused later?
(Time just before 28:00)
S: Well, I guess, like, if you apply the same force to different sized objects, the little one's gonna feel it more, you know?
I: If you do it over a smaller area?
S: Right.
I: OK.
S: Like, the smaller A is, the larger P is given a constant F. So...
I: And that feels different? To... two different things?
S: Yeah. I don't know, like... I guess if you have a... I don't know, I can't really think of an example right now, but it makes sense to think of it like that.
I: All right. Um... any other... I think, yeah... we're about done. Any other comments about this tutorial or this topic or... TA interactions that you want to make at this point?
S: Well, just we switched, uh, phases from solids to liquid, and then...
(Time 29:00)
I: So that was... uh, I mean, that was a big deal for your group?
S: Yeah, like, we're used to thinking of physics as hittin' stuff and pushin' stuff, and used to thinking of solids.
I: I didn't think that that would... well, I mean, like I said, I didn't make these, but... I didn't... I've not seen such a... dramatic, you know, change in the opinion of these things from phase to phase, but it makes sense now that I think about it.
S: Well they just... I don't know, we're used to dealing with solids more than liquids, and we can understand solids better than liquids. So using liquids was a little bit harder, and... it seemed like the way the tutorial was set up also changed at the same time, so we had a hard time with it.
I: What do you mean the way it was set up?
S: As far as... not teaching us the equation, you know... how to derive it ourselves.

I: OK.
S: Like we did in the past. To just say... here's the equation.
(Time just after 30:00)
I: Well, I hope you see that in class eventually, but, I mean, you might not get tested on this, from what I heard, so... we'll see about that.
S: Well, see it next semester, when I have to take 122.
I: Uh, I don't think pressure will come up then?
S: Nope?
I: No.
S: Oh.
I: And you said you're taking [professor] again?
S: Yeah, I have to.
I: Right. Um. So, that's all about this, so I'll stop.
(end of tape)

Interview 11: Tutorial wrap-up

Here, Patty discusses tutorials in general: how they relate to labs, how they help (or do not help) on homework, and other summarizing thoughts.

(Time 0:00) (tape is muffled)
I: Right. I think this is... this is set up... so, like I said, I didn't have a lot to ask about specifically for this tutorial. I just basically wanted to know... how did it go?
S: It was pretty self... I don't know, it was pretty easy, like, all our predictions were what happened, and we found out the equation
I: And you got through it all quickly enough? [Yep.] With... I mean... I mean, how long did it take, about?
S: We had about ten minutes to spare at the end.
I: OK. What... what equation are you talking about? That, uh...
S: Um...
I: That you said you figured out?
S: (quietly) This one.
I: This one. Um... m1 over m2 equals change in t2 over change in t1. OK. And... and so, there was nothing controversial or nothing that you had to work through?
S: Well, we had 'em flip flopped at first. We had t1 on the top, and t2 on the bottom. So then we're, like, oh yeah... (?)
(Time just after 1:00)
I: That... OK, so... (pause) like, m1 times t1... or... time change in t1 equals m2 times change in t2 cause if one's big, then the other is small? Is that right? OK. Um... let's see. (pause) I might take a look at this later, but... since it's toward the end, we don't even do this tutorial every time. It... in the past it's been given as an ILD. Have you been doing ILDs in the class? In lecture? [yeah] Still?
S: Um, we do them, but I don't really get as much out of them as I do tutorials. Like, I actually think the tutorials are a good way to learn, like, I get a lot out of them, but the ILDs... I don't really... maybe just because it's a smaller class with the tutorials, and you're in a set group of four every week.
(Time just before 2:00)
I: OK. Um... so, a lot of what I want to do now is talk about the tutorials in general and some of the ways that it ties in with... with other parts of the class. And so you've already actually started doing it. Um... so... let's see, what was, I guess, the first... the first question then? Um... were the... overall, were the tutorials helpful for you on... in doing homework?
S: The homework?
I: Yeah.
S: Um... a little bit, I guess.

I: How did they help you on the homework?
S: When there were similar subjects as the tutorials and homework, they would help, cause I could be like, "oh yeah, I remember we did this in tutorial. This is the equation we're supposed to use."
I: OK. Now, there were cases... there were cases where the tutorial and the homework didn't line up very well?
S: Well, yeah. There were tutorials... not every homework was in a tutorial, not every tutorial tutorial was in a homework.
(tape quality improves)
(Time just after 3:00)
I: OK, so the... like, the tutorials that weren't in homework didn't help on homework?
S: No.
I: At all? It has... it has to be directly related? I mean... you have to look at a homework question, say to yourself, oh, I saw this in tutorial?
S: Or something related to it, I guess.
I: OK. What would you do in a case like that? Where you saw a homework question, and it looked familiar, looked like something that you had done in tutorial?
S: I'd just look at my tutorial papers, and then...
I: I mean, what do you look for?
S: Uh... I look for, like, the certain problem where, I dunno, if you're doing a homework problem where you're pushing something, and I'm like "oh yeah, we did the tutorial where we're pushing a box," and I'd go and read how the... the experiment was set up, like... what was all the factors and read that, and then I'd read the answer that we decided upon in tutorial and how we got it. You know, that would help in homework.
I: OK. Do you have an exam this week?
(Time just after 4:00)
S: Yes. *cough* excuse me.
(Tape quality improves again after having degraded a bit).
I: OK, um... you might... you might not have, uh, (pause) an impression of this cause we've only done one exam, but... was the tutor... were the tutorials helpful for you in doing the first exam?
S: Not really. Uh, well, I think my hardest thing with the exam was there's only four questions. Um...
I: Mmmhmm.
S: Even though it took a while, there was still... so, there was only, like, four concepts that were covered. Um...
I: Do you have it with you?
S: I should.
I: Do you... have all... all of your tutorial texts with you, too? Cause actually another thing I'm wondering about if I could copy... if I could copy these sometime.
S: Yeah, I have em all. (?)
(Time 5:00)
S: Let's see, I don't... I don't think we covered any of these specific things in the tutorial, so no, they weren't much help. Oh, the last one we did a little bit. The one where we were just talking about Newton's laws in general.
I: OK.
S: So I was able to remember something we did for tutorial. Yeah, cause this last one was an essay one talking about, uh... conflicting with intuition, and we did a tutorial on that.
I: OK, um... so, so there's some slight overlap, um... between the tutorial and other stuff, like... if the tutorial and homework are about the same thing, then you can look up the tutorial and see what you did. If the exam asks you a question about... about intuitions, and your tutorial has done that, then you can cover it.
S: Mmmhmm.
I: Right. But in other senses, it wasn't helpful?
S: Well, the tutorial, like, even if a topic is not tested on an exam or homework, I mean, it's still... a physics topic, so it's useful to know, and maybe I'll be tested on that in another physics class.
(Time after 6:00)
I: OK, um... (pause) so, I mean, this exam... this exam, most of it you said, you know, the tutorials aren't explicitly helpful with. I mean, could you picture some... I mean, some kind of exam, what

kinds of questions would we ask that you could look at it and say, "Yeah, the tutorial is definitely worth it here, it would definitely be rewarding to keep going"?
S: Well, each tutorial covers a certain topic. And... an exam that covered each of those topics or had specific questions relating to each of those topics would definitely help. Um... the problem with that, it might be a little too easy, maybe. They could probably make it so it's not so easy, but they could make it directly relating to the tutorials.
(Time just before 7:00)
I: OK, um... (pause) let's see. (pause) OK. On the exam, for example, there was a, uh... there was a question where you had to draw a free body diagram of a ladder, um... you know, show all the forces acting on it. Talking about what the ladder does. Um... that was un... was that unrelated to tutorial? To the tutorial we gave you about free body diagrams? Or does it seem different for some reason?
S: It seems different cause it's on an angle. This... this problem here was more relating to a homework problem we had at one point. But...
I: This is closer to a homework?
S: Yeah.
I: Do you remember what the homework question was?
(pause)
S: Um... something about a free body diagram. Let's see. (pause)
(Time 8:00)
S: I think it was with a sled or... oh, this one. I think it was this one.
I: Mmmhmm.
S: Pulling a book, where you have a string attached to a book.
I: Let's see what week this was... homework 4. OK. Pulling a book.
S: Yeah, they wanted you to draw a free body diagram.
I: OK, and so you had done this with the book, and that looked... I mean, this ladder problem reminded you more of that than it did...
S: Yeah, I think because it was on an angle, and I don't remember having... doing anything with an angle in... in tutorial.
(pause)
(Time before 9:00)
I: OK. So, right. No sense to keep... looking through that too much, I guess, unless you want to find... oh, there's the book problem right there. (pause) *cough* OK. Um... so let's see... what... so... the tutorial didn't overlap explicitly with the homework that often, but it did sometimes, right? Um... it happened to overlap pretty well with a question on this exam, but only, like, one of them.
S: Yeah.
I: Something like that. Was that enough reason to keep going to tutorials, or did you keep going for another reason?
S: Um, I think I kept going... well, first of all, it was required, and then because, just like... it was the... I don't know, honestly, the three aspects of this class: lecture, tutorial, and lab, I felt like I was getting the most out of tutorial, so I was like, "I might as well get something out of this class."
(Time just after 10:00)
I: Oh, so... so because... so it was more because lecture wasn't effective for you, or you didn't think it was.
S: Right, I guess.
I: All right. What's the issue with lab? I mean, I know we've talked about lecture before, but why do you feel you didn't get a whole lot out of the lab, then?
S: Uh, well, I get stuff out of it, I guess, but there's less teaching and direction in lab, so you just kinda have to, you know, go... and we don't really have any instruction, so...
I: It's kind of open-ended, right?
S: Yeah.
I: OK.
S: Whereas in tutorial, we have specific instructions, you know, certain questions to answer each step, then check with the TA and you're on a set track. And you know... you know you've covered what you're expected to cover, and you're able to learn what the idea of the tutorial is.
I: You can get out of the lab not having an exact answer, or... uh...
(Time 11:00)

S: Well, lab, you never seem to know if you're doing it right. Like, it just... you know, ask another group, "So, what'd you get?" "Yeah, I got that." "I didn't know, we just did this." "OK, that sounds good."   "What'd that group get?" "I don't know. What are you guys doing?" You know? And the TA is not really allowed to tell us anything.
I: Do you ever get... do you ever get that impression in tutorial: that the TA isn't allowed to tell you stuff?
S: I seem to get the impression that the TA doesn't want to tell us stuff in tutorial, whereas in lab he can't. I don't know why I get different impressions.
I: So, there's a difference, like... like... wait, what do you mean in the lab the TA can't tell you? Is unable or is not allowed?
S: Not allowed.
I: All right. And in tutorial, what do you think it is?
S: I... I think in tutorial, it's more like teaching, and he wants us to figure it out on our own, so he's not gonna tell us the answer, but eventually he will if we're, like, stressing out about it or we can't figure it out. Then he'll tell us. Whereas in lab, he's like "I can't," you know, because that would be cheating, cause we're graded on it, I guess.
coughs
I: Coughing all of a sudden. Um, all right. So... so tutorial was the most helpful part. Um... at what point... or, I'm sorry, I shouldn't have asked that. How did I phrase it? At this point, what does it mean to you to have... you know, "gotten" the concept or understood the concept fully through tutorial? I mean, how do you know going through a tutorial, "oh, I just got it this time. I got it. I understand this."
S: I guess if our answer makes sense to us and completely answers the question, and it doesn't conflict with anything later on in tutorial, and then the TAs come over, and if they don't say we did it horribly wrong, then we figure we did it right. I mean, a lot of the things are not that difficult, they're just like switching your way of thinking a little bit.
(Time well after 13:00)
I: Mmmhmm.
coughs
I: So, it's just... it's just gotta be something that makes sense, and the TA can't come by and say it's wrong?
S: Basically.
I: And then, that's it.
S: Usually, you know, out of the four of us, one... two, three, usually all... get the same thing.
I: *coughs* So, by the end, you think you've gotten the point. OK. So... I mean that's usually associated, you know, with the various concepts, like... one tutorial will be about momentum, one will be about Newton 3, one will be about free body diagrams. Um... do you feel you... need to have gotten the point of those tutorials to do the homework, or can you do the homework without... without that level of understanding you just described?
(Time 14:00)
S: Um, you can do the homework without it. It's... helps if you have that little understanding. Um...the tutorials more on... well, it seemed to be the tutorials are a combination of concept and problem solving, and the homeworks are specifically problem solving.
I: Mmmhmm.
S: You can solve problems without understanding what's going on. You just... you know, find the right equation and plug it in, and get an answer that make sense, sure... and you don't really know what's going on in the equation.
I: Were there any weeks or any particular homework assignments you felt you had to resort to something like that?
S: Oh, a lot of em. Usually a couple problems on all of them, I think.
I: OK, and... and... so, why do you think you had to resort to that? I mean, are those weeks you didn't understand the tutorial as well, or... or was it time when the tutorial didn't match up that well with what the homework was asking?
(Time just before 15:00)
S: Uh, it's probably more often that it didn't match up. Um... maybe the biggest reason was I just didn't know what they were asking for on the homework. [Mmmhmm] Like, the question was kinda

vague.
(pause)
S: Or the tutorial and the homework did match up, but it was a tricky concept, and I just never fully grasped it.
(pause)
I: OK, um... but... in the cases where you felt you completely got it, was that enough for you to do well on the homework? Did you do OK on the homeworks in the cases where you came out of the tutorial thinking you really got it?
S: Um... for homeworks that dealt specifically with tutorial stuff, I'd say yeah, that was helpful when I really got it. I did the homework with confidence.
I: You know, understanding the tutorial enough was enough to get you through the homework OK [yeah] when they overlapped? OK. Uh, overall, I guess the homework... was it easy, or hard, or were there questions sort of a mixed level of difficulty?
(Time 16:00)
S: Easy or harder than what?
I: I mean, just in general, would you call them easy or hard?
S: Um... I thought a lot of them were hard. I think... maybe my biggest problem is I didn't know where to start, so I'd always find a friend who was good at physics and be like, "am I doing this right?" And... just to kind of get me started on it.
(pause)
I: Were there some that seemed obviously easy to you?
S: The last one we did was all on astrophysics, and that came really easy to me, cause I... I had taken two semesters of astrophysics here.
I: Cause you took astrophysics already?
S: Yeah, and I...
I: What kind of questions were we asking about astrophysics? I haven't been following the homework.
S: Oh, about how things orbit, and how gravity is related in or... in orbiting a planet.
I: Like, like, like... calculating gravitational forces between a planet and something rotating around it?
(Time before 17:00)
S: Yeah. Um... the first question was just about... (pause) homework 10... the first question was just about... an essay question. How do things orbit? And just explain how gravity's involved in... orbiting, and a lot of the other ones were... calculate the mass of this planet, calculate the distance.
I: OK.
S: Stuff like that.
I: Um... so you say you handled the ones that seemed harder to you, uh, by... you'd ask someone about it. Would you try it first, or ask them... you know... at what point in the problem solving process do you ask someone for help?
S: Uh... when I get stuck. I'd usually do my homework, just... with someone who knew it, and when I hit a problem... when I hit a bump I'd... I'd ask them for help. Sometimes I'd do, like, two or three problems, then I'd get to another one, and I'd do half of it, and I'd be like, "Oh, what's this part?"
(Time 18:00)
I: Mmmhmm.
S: So...
I: Does this relate at all... I mean, sometimes your group had... um... tough tutorial questions to deal with [mmmhmm] or... I mean, I've seen groups even have trouble, when you're doing the loop-de-loop lab, figuring out theoretically how high the marble should be released before you drop it. Um... sometimes you've had to deal with hard questions in tutorial also. Um... do you deal with those the same way, you think, or is there something different going on between, you know, when you're working on a hard homework problem and a hard tutorial question?
S: When I'm working on a hard homework problem, I can get answers. I can go to the book, I can go to other people, and I can get specific answers to specific problems.
I: I mean, they can... what do you mean get answers? You can talk to someone that knows it, and they can tell you what the answer is?
S: Well, not just, like, what's the answer to the homework problem... [uh huh], they can explain the concept as in, like, I don't know how this part of the concept works, and they can be like, right there,

they tell me the answer. Or I can look at it in the book and it's right there. I can find out the answer.
(Time just after 19:00)
I: Mmmhmm.
S: Whereas tutorial, like, they have this roundabout way of doing it, and... you can't really cover every angle of every question, I mean, it would just take a long time, so... sometimes there's other stuff that you're just wondering, and you can't get the answers from it.
(pause)
I: You can't get the answers from...
S: Well, like, with temperature... let's see... um... I don't know if there was a specific example here or not. But, you know, there's just... you can look at how temperature works in a various number of ways. Like, OK, we... we defined it as the amount of heat present. Well, what if someone's thinking "well, what about cold? Doesn't that matter?" And... I came from a point that cold doesn't exist, it's just the absence of heat, but if someone was thinking there's this interaction between something called heat and something called cold, and they didn't know that, then they would be confused here. Um... but if you had a person or a textbook with a paragraph explaining this, then they could be like, "oh, OK, now I understand!" But there is no... there is no explanation of what temperature is, of what heat is... it's just...
(Time well after 20:00)
I: So, tutorial doesn't answer all the questions you could possibly have about it?
S: Right.
I: But the book or someone else that's knowledgeable about it would be able to handle that better?
S: Right.
I: Am I getting that right? OK. I think I follow what you're sayin'.
S: More like 90% of your questions, you know. They can't possibly know everything, but...
I: Right... but, but... tutorial leaves... I mean, leaves more blank, you would say, then?
S: Um, I think they, in general, do a pretty good job, but it has the possibility of leaving blanks. It doesn't always, because it just depends on a certain person, on what questions they have. On what angle they come at it.
(Time 21:00)
I: Mmmhmm.
S: And sometimes, for me, sometimes there's blanks, and sometimes there's not.
I: OK. OK. So, stepping back from tutorial, this is just sort of overarching kind of thing... I can't speak for the specific professor, but, you know, I've seen this course get designed before, and it's typically designed so that different parts of the course sort of work together coherently. Like, they're designed to work together. Um... do you think that's the case here with this... with this course so far, or no?
S: Um, I've seen lab and tutorial correlate sometimes. Like, when we did the loop thing, the one tutorial we didn't finish, that correlated very well.
I: Mmmhmm.
S: Um... it doesn't always match up week to week, but sometimes there's, like, remember that tutorial we did two weeks ago? Well, this is it in lab. As far as the lecture is concerned, I don't know, it doesn't seem to match up very well, because...
I: What doesn't match up?
(Time just before 22:00)
S: I can't... don't know if I remember specifics, but it just seems like in lab, Brian's always saying... or in tutorial, Brian's always saying, "didn't he cover this in lecture?" We're like, no... and then maybe a couple weeks later, he will, but... it's like... we're doing this in lecture, it doesn't have anything to do with this.
I: So, most of the comments that you're making are about specific bits of content, right? About... um... you're talking about the tutorial you didn't finish and the loop-de-loop lab, those consisted of talking about a specific bit of circular motion, right?
S: Right.
I: And there was some times when Brian was surprised that [Professor] didn't cover a certain topic in lecture.
S: OK.
I: Right before tutorial, so that... that... that's content related. Um... were they... were they, like, the

different parts of the course reinforcing or contradicting each other as far as, you know, what's important for doing well in this class, what kind of things you need to do to do well on homework, tests, learning concepts, that sort of thing?
(Time 23:00)
S: Uh, I thought they did a pretty good job correlating there, as far as what's important for tests and homework.
I: I mean, so... I mean, what kind of message did you get from a bunch of different things, then, if they work together?
S: Well, it's... I think the timing may be off for things, like... they don't contradict when they talk about the same topics, it's not like... they're defining Newton's laws in different ways. But, it just... the timing doesn't always match up, and as far as what we're expected to do on the exam, I think [Professor]... [Professor] does a good job of telling us what to expect. I mean, on this one, he was like, there's gonna be four questions, one's gonna be an essay, and one's gonna be estimation, and the others are gonna be problem solving, so... that was...
I: Wait, so there's estimation, essay, I mean, problem solving... would it seem... I mean, the homework and the exams, do they pretty much agree on the type of questions you would see?
(Time 24:00)
S: Yeah, I'd say the... the two problems in here that were.... that were the problem solving ones were pretty well like homework ones.
I: In the homework, but, OK... so we've already explored the... the connection between tutorial and homework.
S: No, I was talking about the exam.
I: No, I know, I mean, you were connecting exams with homework, and we had already talked about connecting homework and tutorial [OK] so, I can sort of piece that together. So, I guess one last... um... sort of con... context-specific, I guess... a pencil someplace I can? I'm just gonna write an equation down. So, there's an equation that you can see in physics class, and you may have used on homework before. That... goes something like this. v equals v naught plus a delta t, right?
S: Mmmhmm.
I: OK, do you recognize... do you recognize that?
S: Yeah, we used it before.
(Time 25:00)
I: OK, do you know... why is that true?
(pause)
S: Well, your velocity is going to equal whatever you start out with and if you're accelerating, that's gonna matter, like, the time, and that's gonna affect your velocity, but if you're not accelerating at all, that would be... not affecting your velocity.
I: So v would just be v zero? OK, so... if someone... if someone hadn't had physics before, and you were trying to get this idea across or teach them this equation, how would you do it? Would you explain it just like you just did to me, or...?
S: Probably start out that way, but... well, it depends how much physics they knew. Um... like, if they got that, then I guess I'd stop there. I'd probably use an example to explain it to them.
I: Like what?
S: Oh, like... car moving at a constant velocity, and then I'd show what... what parts of that movement relate to which variables in this equation. And then I could show another car moving at... accelerated velocity.
(Time after 26:00)
I: Mmmhmm. OK. Um... would you call the stuff you've described to me... would you call that common sense, or not?
S: Yeah, I'd call it common sense.
I: Well, why would you call it common sense?
S: I don't know. I call things "common sense" that I'm familiar with and that I've been familiar with for a long time. It seem... you know, if you're moving at some pace, what are you moving at? You're gonna be moving at that pace, unless something changes. And [mmmhmm] change is acceleration, so, unless you're accelerating, you're gonna be moving at what you start out with.
I: And the second term here, the a delta t is just the change?
S: Right.

(Time just before 27:00)
I: OK, and that makes sense. All right. So, I think that's all for the specific questions. Like I said, I'll get back to you if, if we need to talk about any of the surveys, but it wouldn't be much longer than, um, you know, what we've just done. Just this half hour, which is roughly how long we've gone. Um... I don't know, see, I don't know when I'm gonna get to start looking at this, I actually haven't listened to any of the tapes since we've done 'em, I just haven't had time to do that, been working on other stuff. But other things may arise, or, you know, we may look at survey results, and decide we want to follow up. Would you be available to do something like this maybe once or twice next semester?
S: Sure.
I: If I get a hold of you?
S: Just email me.
I: OK, and... and, you know, like I said, we'll talk about if we need to do it next week, but I don't think we would need to do it much beyond then. We would be done. Um... maybe next time, also, we could arrange a time, I mean, you have an exam coming up Wednesday, right? So you need all your stuff?
S: Yeah.
I: OK. So, I'll need to photocopy things eventually, and so I'll get it from you then. Maybe we can actually talk about how the test went, too.
(Time 28:00)
S: OK.
I: But I think that's it for now.
(end tape)

Appendix E: Sample epistemologized tutorial: Newton's Third Law

Here is the order of items for our epistemologized Newton's Third Law tutorial. The reflective questions at the end are not included in the University of Washington tutorials that inspired our work here.

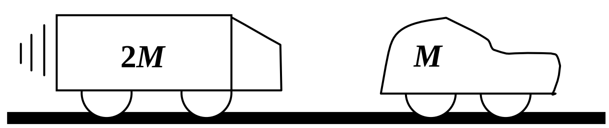
The main point of this tutorial is helping you learn more strategies for learning physics concepts that seem to defy common sense.

I. Newton's third law and common sense

According to Newton's third law, when two objects interact,

The force exerted by object A on object B is equal in strength (but opposite in direction) to the force exerted by object B on object A.

Often, this law makes perfect sense. But in some cases, it seems not to. Consider a heavy truck ramming into a parked, unoccupied car.



A. (Work together) According to common sense, which force (if either) is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck? Explain the intuitive reasoning.

B. (Work together) We've asked this question of many students, and a typical response goes like this: "Intuitively, the car reacts more during the collision. (You'd rather be riding in the truck!) So the car feels the bigger force."
Is your group's explanation in part A similar to or different from this? Explain.

C. (Work together) According to Newton's third law, which of those forces (if either) is bigger?

D. Experiment. There will be a spring-scale demo (with pulling forces) where a small person will pull a larger one. What are the results? What if the people are reversed? You get something similar with collision situations (where the forces push).

II. What to do with the contradiction between common sense and Newton's third law?

Before moving on to the next part of our Newton's third law lesson, let's consider the contradiction we just found between physics and common sense.

A. (Work individually) In summary, for most people, Newton's third law contradicts the common-sense intuition that the car reacts more during the collision. Which one of the following best expresses your attitude toward this contradiction?

i. We shouldn't dwell on these kinds of contradictions and should instead focus on learning exactly when Newton's third law does and doesn't apply.

ii. There's probably some way to reconcile common sense with Newton's third law, though I don't see how.

iii. Although physics usually can be reconciled with common sense, here the contradiction between physics and common sense is so blatant that we have to accept it.

Briefly explain why you chose the answer you chose.

B. Discuss your answer with your group. Is there a consensus or do people disagree?

III. A new strategy: Refining intuition

Before accepting that there's an irreconcilable contradiction between Newton's third law and the intuition that the car reacts more during the collision, let's try a reconciliation strategy called refining your intuitions.

A. (Work together) We'll start with a new question. Suppose the truck's mass is 2000 kg while the car's mass is 1000 kg. And suppose the truck slows down by 5 m/s during the collision. Intuitively, how much speed does the car gain during the collision? (Apply the intuition that the car reacts more during the collision, keeping in mind that the truck is twice as heavy.) Explain your intuitive reasoning.

✯ Consult an instructor before you proceed.

B. Does your answer to part A agree with Newton's third law? To find out, we'll lead you through some quick calculations.

1. Suppose the car and truck remain in contact for 0.50 seconds before bouncing off each other. Calculate (a) the truck's acceleration during the collision and (b) the car's acceleration during the collision (assuming your guess about its change in speed is correct).

2. To good approximation, the forces that the car and truck exert on each other are the net horizontal forces they feel during the collision. Starting with the accelerations you just calculated, use Newton's second law (the one relating net force to acceleration) to find (a) the force felt by the truck during the collision and (b) the force felt by the car during the collision.

3. The accelerations and forces you just calculated were all based on your guess about the car's gain in speed – a guess based on the intuition that the car reacts more during the collision. Does that intuitive guess agree or disagree with Newton's third law? How do you know?

✭ Consult an instructor before you proceed.

IV. What just happened?

A. (Work together) We need to sort out what to do with the car-reacts-more intuition, i.e., the idea that the car reacts more than the truck during the collision. At the beginning of this tutorial, when you answered a question about the forces acting on the car vs. the truck, that intuition led to a wrong answer that disagreed with Newton's third law. But in section III above, when you answered a question about changes in velocity, that same intuition led to a right answer that agrees with Newton's third law. So, what's up with the car-reacts-more intuition? Is it wrong? Is it right? Is it something else? Explain.

B. (Work together) We now see that the car "reacts" more during the collision in the sense that it undergoes a greater change in velocity, i.e., it experiences a larger acceleration. Give a common-sense explanation for why the car reacts (accelerates) more during the collision even though it feels a force no bigger than the truck feels. Ask your TA for a hint, if needed. This is the second most important question in the tutorial.

C. (Work together) We intended this tutorial as a lesson not just about Newton's third law, but also about strategies for learning physics concepts that seem to contradict common sense. What general strategies are suggested by this tutorial—strategies you might be able to use with counterintuitive concepts appearing later in the course? This is the most important question in the tutorial.