Investigating Student Epistemologies in Physics 11 at Tufts University

An honors thesis for the Department of Interdisciplinary Studies

Mary Sypek

Tufts University, 2013

Table of Contents

Abstract

Student epistemologies in Physics, their ideas about knowing and what kinds of knowledge are valuable, affect learning and have been the subject of many recent reforms in Physics education. This project is an investigation into student epistemologies in a reformed introductory Physics course at Tufts University. I interviewed fifteen students between four and sixteen months after completing Physics 11 at Tufts, and used their words to find evidence of their epistemologies about Physics. I found that students who understood the epistemological goals of the course generally also liked the course, and students who did not understand these goals generally did not like the course. Underneath these general classifications, I found some more specific, focused variability in student epistemologies, which is the subject of the second conjecture. I conclude with suggestions for future research, which I hope will expand this exploratory study and build upon my findings here.

Introduction

This project is an investigation into student experiences in Physics 11 taught by David Hammer and ways students think about science learning in response to course practices. This project began because of my interest in the ways science is taught at Tufts and how different approaches affect student attitudes about science, their success in understanding and retaining information, and their willingness to pursue science at Tufts or in professional settings.

As a Biology major at Tufts, I have taken four introductory-level science courses (Biology 13/14, Chemistry 1/2). These courses generally enroll between one and four hundred people and involve a traditional lecture and laboratory format. As a student in these courses, I felt like I was not learning in a way that was true to the nature of science as a discipline. My role in those classes seemed to be to collect relevant information as it was passed to me, memorize that information, and be able to use it well enough to answer exam questions. I was told what was important, and did not feel like an agent in my own learning.

My motivation to do this project arose from those experiences. I became passionate about finding educational experiences for science students that would allow them to "play a different game" (Ford, 2005). I began this project hoping to learn about current movements in undergraduate science education reform, tap into the conversations happening at Tufts, and see whether a reformed course was successful in students think about their learning and learn more effectively. As I developed my project further, two questions emerged: 1) What are current and recent reforms in science education, and what are they revealing about student learning? 2) How do course practices in Physics 11 affect student epistemologies and attitudes about science?

This paper begins with a review of relevant literature about student epistemologies and current reforms in university science education, as well as some background on Physics 11 and my methods of studying it. It continues with two data based claims:

1. When generally categorized, students who understood the epistemological goals of Physics 11 were also students who liked the course, whereas students who did not like the course generally did not understand the epistemological goals behind it.
2. Though students can be classified in a general way, there is significant variability in each student's experience that challenges this general classification.

The paper concludes with my suggestions for ways to study these ideas further. I am grateful to be able to share my research with the Tufts community, and hope to generate some meaningful discussions with this project.

Literature Review

My review of relevant literature is in four parts. First, I discuss student epistemologies, in general and in science specifically. Then, I discuss the fact that students' epistemologies can affect their learning and are therefore important as a subject of study and a site of reform in science courses. I continue by discussing current curricular and pedagogical reforms in university-level Physics courses, and how they tacitly or explicitly address student epistemologies. Finally, I describe how the research I discuss in this paper fits into this body of literature because of the focus it places on studying student epistemologies several months after students took a reformed Physics course that was explicitly focused on shifting student epistemologies, and how this focus is relevant to the study of science education as a whole.

What are student epistemologies, and epistemologies in science?

Epistemologies, defined generally as the ways people come to know as well as the theories and beliefs they hold about knowing (Hofer and Pintrich, 1997) have been a subject of study in education and psychology for several decades. In earlier research, as reviewed by Hofer and Pintrich, epistemologies were studied as general thoughts about what it means to know, learn and understand (1997). For example, through several longitudinal studies, Perry developed a scheme of classifying the "structural aspects of knowing and valuing" in college students, implying that the way that college students find meaning in their educational experiences is not a function of their personalities but instead something that can change and be developed (1970, 14).

More recent research has challenged Perry's one-dimensional scheme of epistemological development, suggesting that a student's cognitive development is more complex and should be considered as such. Additionally, research began to focus on epistemologies as they affect specific disciplines of academics. Schommer, who suggested that epistemological development should be considered in five different dimensions, found that in college math courses, the less students believed in "simple knowledge," the better they did on mastery tests and the more accurately they were able to assess their comprehension in the course (Schommer, Crouse and Rhodes, 1992).

Among these studies of discipline-specific epistemologies are several that focus on epistemologies in Physics. Elby defined students' epistemologies in Physics as views about the nature of knowing in Physics, and expectations as views about what kinds of knowing and learning are rewarded in Physics classes (2011). A framework of common epistemologies in Physics has also been developed using a series of spectra (Hammer 1994). For example, students hold beliefs about the structure of Physics knowledge as composed of isolated pieces or one coherent system. They also can hold beliefs about the content of Physics as a series of formulas or a series of concepts, and the learning of Physics as transmitted by authority or constructed by students. Using these spectra, Hammer and others have classified students' experiences in Physics and beliefs about the discipline and have developed ways of studying and attempting to shift these beliefs so they are most productive for students.

Additionally, Hammer and Elby challenged those who had previously challenged Perry's and others' beliefs , saying that they should be considered in multiple dimensions (2002). Hammer and Elby maintained that even those who believed in epistemologies as multidimensional still also believed in a unitary ontology, or form, of epistemologies. This unitary ontology holds epistemologies as beliefs that are consistent across contexts, and that are replaced in students' minds as they are disproven. They questioned the presumed ontology of epistemologies, suggesting that this default view was not based in literature and should be reconsidered. They proposed an alternative framework of epistemologies as "finer-grained resources" and called for future research that would define what those resources were and how they are affected by the context in which a student learns or uses them. Thinking about epistemologies in this way has become the basis for much current research in Physics learning.

Epistemologies are important, and affect student learning

In a study of the types of reasoning used in science courses, it was postulated that classifying these types of reasoning is important because, "this sort of knowledge *about* science might reasonably be regarded as an essential component of an understanding of science, and therefore as an intended outcome of science education (Leach, Millar, Ryder, et al, 2000, 498). Indeed, several studies have shown that students' epistemologies can affect their learning of Physics. For example, Jan's experiences in an introductory Physics class showed that when students have a barrier between formal and everyday reasoning, they have trouble learning Physics (Lising and Elby, 2005).This study focused on Jan, a student who had trouble mastering her college Physics class. In the study, Jan's formal reasoning was the reasoning she considered to be appropriate for Physics, generally that which she had learned in class. Jan also had everyday reasoning, which consisted of her intuitions about the physical world and her explanations of phenomena around her. The researchers found that Jan was able to make connections between her various formal ideas or everyday ideas when solving problems, but that she very rarely reconciled inconsistencies between a formal and an everyday idea. Jan saw no sense in reconciling these different types of ideas, considering them to be different kinds of knowledge. The researchers thoroughly considered plausible causes of Jan's difficulty in this Physics course and found that the only reasonable explanation had to include the barrier in her epistemologies. If Jan were better able to reconcile formal reasoning with everyday reasoning, they concluded, she would have had an easier time in her Physics course.

In another study, researchers showed that students who showed the highest conceptual gains at the end of the course also showed more articulate and epistemologically sophisticated reflection about their learning (May and Etkina, 2002). In a Physics course for first year engineering honors students, students submitted weekly reports about how they learned the specific Physics concepts covered that week. These reports were coded based on the epistemological goals of the course, which generally focused on constructing knowledge using genuine processes of science. At the end of the course, students were tested on their conceptual gains in the course. Researchers found that "high gainers" wrote more about their learning than low gainers and were more likely to connect what they were learning in class to their knowledge of the natural world or their prior knowledge of Physics. Overall, high gainers showed more epistemologically sophisticated reflections throughout the course, suggesting that these epistemological stances are important for student success. With this knowledge, the researchers wonder whether epistemologies and self-reflection should be developed in order to enhance content learning, or whether learning content should be a means of developing epistemologies.

There are many current reforms in college-level Physics, which affect student learning and may affect student epistemologies, especially when these are explicitly addressed

Many professors are making pedagogical and curricular shifts in their Physics courses with the goal of improving students' conceptual understanding. Many of these reforms do not explicitly focus on epistemologies but, in light of previous research, students' increased success in these courses suggests a possible shift in epistemologies as a result of said reforms. Additionally, in a course like Redish and Hammer's, which explicitly focuses on student epistemologies, concrete reforms were shown to affect student epistemologies. Considering these reforms can be useful when considering a specific course and its attempts to produce shifts in students' epistemologies.

In a ten-year study focused on the use of peer instruction in Introductory Physics courses, researchers showed that peer instruction can help students improve conceptual reasoning and quantitative problem solving, as measured using standard assessments of these skills (Crouch and Mazur, 2001). Two Physics courses, one algebra-based and one calculus-based, were studied, and students in both courses improved on assessments of conceptual knowledge. Students in these courses collaborated often and were able to construct conceptual knowledge together. While neither the course nor study explicitly addresses students' epistemologies, it can be posited that in courses where students regularly practice constructing knowledge together and experience increased conceptual understanding as a result, epistemologies are shifting towards viewing Physics as a series of coherent concepts, and knowledge as constructed rather than transmitted.

Students' conceptual knowledge can also be improved by changing the sequence of material covered in a Physics course (Chabay and Sherwood, 2006). In an Electricity and Magnetism course, which contains more abstract concepts that Introductory Physics, researchers wanted to increase students' conceptual coherence, allow them more time to assimilate and master new concepts, give them more concreteness in learning, and facilitate reasoning about complex systems. Again, epistemologies are not explicitly addressed, but it can be argued that students who have a great deal of conceptual coherence also view Physics a series of related concepts. Researchers found that in courses with a revised curriculum, students were better able to solve difficult problems, had a greater conceptual understanding of the course, explained their work better, and were less likely to use solely formulas and algorithms to solve problems. It is possible that such a reformed curriculum encouraged students to think of Physics as a series of related concepts rather than a series of disparate formulas (Hammer 1994).

In some radically reformed Physics courses, the traditional ways of building knowledge are challenged and students decide on meaningful phenomena of study. For example, in SCALE-UP classes, the traditional lecture/lab format is replaced with four to six hours a week of activity-based instruction, with the goal of encouraging students to practice science in a way that is more authentic to the discipline (Beichner and Saul, 2003). These courses have been shown to lead to increased collaboration and increased test scores for students in class. It is possible that this improvement is due to shifts in epistemologies toward a view of Physics as constructed rather than transmitted (Hammer

1994). In a similar vein, ISLE classes have students construct and test concepts, and instructors in these courses explicitly teach the concept of "learning how to learn" (Etkina and Heuvelen, 2001). These courses lead to improvements in students' ability to design and evaluate activities, and improvements on traditional measures of Physics knowledge, like the Force Concept Inventory. Again, it can be postulated that a curriculum such as this can shift students' epistemologies toward thinking of Physics as constructed knowledge.

Building on this work, Redish and Hammer found that a course with an explicit epistemological curriculum produced noticeable epistemological shifts in students (2009). The course, composed primarily of life-science majors, focused on helping students to "think scientifically," defined more specifically as striving to build coherence, thinking in terms of mechanisms, and following the implications of assumptions. Researchers used a combination of specific reforms to achieve these goals, many of which are worth noting. For example, in lecture, significant time was given to discussing productive epistemologies, using vocabulary such as "shopping for ideas, sense making, seeking coherence, restricting the scope, choosing foothold ideas, and playing the implications game" (p. 631). Clickers were also used in lecture, but it was noted that students always practiced arguing for multiple answers rather than simply receiving the correct answer from the professor. This encouraged the epistemology of Physics knowledge as constructed rather than transmitted. "Interactive Lecture Demonstrations," were used to help students practice reconciling their intuitions with reality. During these, an entire lecture was devoted to a series of demonstrations with the goal of presenting students with conflict and helping them reconcile their intuition with reality. Other aspects of the course, like lab, quizzes, tests, problem sets, and discussion sections (replaced with "tutorials"), were used to enforce the explicit epistemological learning students did during lecture.

Researchers used each aspect of this course to "tap into" students' productive conceptual and epistemological resources, and made frequent statements about productive epistemologies in Physics. They administered pre-post conceptual and epistemological surveys and found enhanced gains on conceptual tests but unexpected gains on epistemological surveys. They concluded that for these students, an explicit focus on epistemologies in Physics proved beneficial in developing students' epistemologies in the course. They suggest using similar reforms to help students learn to focus on epistemologies and therefore find increased success in Physics courses.

Situating this study within previous literature

This study focuses on a specific introductory Physics course that has an explicit epistemological curriculum and is only in its third cycle at Tufts. The course, described more fully in the next section and in anther of Hammer's papers (2012), follows from Redish and Hammer's course at the University of Maryland, but differs from that course in some notable ways. It also differs from other introductory-level science courses at Tufts. Given that Redish and Hammer found noticeable epistemological gains in their course, is it possible to transfer this success to another context? How will the course practices that are specific to this course affect student learning? It is possible that a study of this course will provide additional insights into effective reforms in Physics courses.

Additionally, all reformed courses that have been studied thus far have focused on student's epistemologies *during* or *immediately following* their Physics course. It is reasonable to claim that the most effective reforms would encourage lasting epistemological shifts in students, that could be noted months or years after the completed course. In this study, I interviewed students anywhere from several months to over a year after they completed the course of interest, which provided a new perspective on their epistemologies and the effectiveness of the reforms used in this course. This method of research could be incorporated into other studies so as to study the long-term effects of course reforms, and the lastingness of epistemological shifts in students.

Description of Physics 11

David Hammer's version of Physics 11 is a unique course because of the philosophy behind it and the course practices used within it. The course has an explicit focus on helping students develop useful epistemologies for learning science, and some of the practices used throughout the course are different from those used in other introductory science classes at Tufts. This course is in its third cycle at Tufts and is taught by David Hammer, who worked on developing, teaching and studying learning in similar courses at the University of Maryland with Edward Redish for several years. Physics 11 follows from those courses in many of its reforms, and also contains some practices of its own. At Tufts, Physics 11 involves two one hour and fifteen minute lectures per week, along with one fifty minute mandatory recitation section and one three hour laboratory section per week. Weekly problem sets are given, along with two in-class examinations and an in class final examination.

The uniqueness of Physics 11 starts with the philosophy behind the course. For the purposes of this paper, I will discuss five "epistemological hallmarks" of Physics 11. These are major aspects of the philosophy behind the course that are integral to understanding the specific course practices used. They are goals for student thinking, ways of thinking that have been shown to aid in student understanding of Physics. I will then discuss specific course practices that encourage students to use these epistemological hallmarks.

The epistemological hallmarks of this course, as I see them, are as follows:

I. Starting with intuition: where can we get from what we know?

II. Thinking about learning: thinking about how we think about Physics

III. Using peers' opinions and argumentation to find useful answers

IV. Seeking and sorting out confusion

V. Mathematics as an expression of ideas

The first epistemological hallmark of Physics 11 is the idea of starting with intuition. Hammer encourages students throughout the course to start with what they know and work from that to understand what they don't know. Prominent on the syllabus is the quotation, "Science is nothing more than a refinement of everyday thinking. – Albert Einstein" ("Physics 11 Syllabus"). Indeed, the philosophy of this course is focused on encouraging students to practice making sense of the world around them by starting from what they already know about the way things move, thinking that has been pretty reliable to them thus far in life ("Physics 11 Syllabus").

A second epistemological hallmark of this course is an explicit focus on thinking about learning Physics. Students are encouraged throughout the course to figure out what it means to learn Physics, and students who do so often meet with more success in the course than those who do not. Hammer peppers each lecture with comments about the "work" of learning Physics. For example, he often encourages students to practice explaining the Physics concepts they're learning to people who never taken a Physics class, because this can show them what they truly understand. He stresses the importance of understanding what it means to learn and what it means to understand, not what it means to do well on an exam or lab report.

A third epistemological hallmark of Physics 11 is using argumentation and peers' opinions to find answers. The course is centered around the practice of discussing Physics. Students are given opportunities in almost every part of the course to talk about the learning they are doing and to pit their ideas against each other's in order to reconcile confusion. For example, Hammer encourages students to work on problem sets together so they can argue for their own ideas and consider others' as they solve difficult problems. A willingness from students to work with each other in order to arrive at answers is important to succeeding in this course.

Seeking and sorting out confusion is not only an epistemological hallmark of this course, but something that Hammer says to students quite often in class. Students are often encouraged to find what confuses them and spend time working with it. In a conversation with Hammer about this course, he said, "Students are to confusion as firefighters are to fire. It's your job. If you are a firefighter, some part of you has to be pretty thrilled that there's a fire. Same thing if you're a surgeon. Some part of you has to think "Cool. A tricky tumor." […] students should be the same way about confusion (Personal Communication)." This idea guides the course and most of the practices used within it, and is contrary to some of the practices seen in other introductory level science courses that focus on repeatedly practicing concepts that students already understand.

Finally, using mathematics as an expression of ideas rather than as a means to an answer is an epistemological hallmark of this course. Hammer focuses on teaching students concepts that are then supported by mathematical algorithms and formulas, rather than on using these to help students arrive at "correct answers." A description of this course's predecessor at Maryland stresses the importance of seeking coherence, and understanding how ideas fit together rather than knowing words or formulas that hold no meaning for students (Redish and Hammer, 2009).

As was mentioned earlier, the epistemological hallmarks of Physics 11 guide the practices used in the course, and most can be seen in each specific component of Physics 11. For the purpose of analysis in this paper, the main aspects of this course are lecture, problem sets, exams, labs, recitation, and office hours.

Lecture involves using Clicker questions to encourage student argumentation and collaboration

The guiding practice behind Physics 11 lecture is the use of Clicker questions. In a recent paper, Hammer describes his approach as, "something similar to *peer instruction*, but with considerable improvisation" (Hammer 2012). He uses questions that are meant to encourage students to hear arguments for multiple answers to a question and to work collaboratively to arrive at conclusions. Generally, a question is posed, students give an answer, and then Hammer asks for arguments for several of the different answer choices. Then, students often have time to talk with one another and vote again, to see if thinking changed. Sometimes another discussion follows, and sometimes a new question is organically generated from the first question. Some Clicker questions in this course only take a few minutes, and some take as long as twenty or thirty minutes.

Lecture and the use of Clicker questions incorporate most of the epistemological hallmarks of this course. Students are encouraged to start with what they know, and often the discussion following a Clicker question involves describing where the question challenged students' ideas about the world and how it works. Because of the way that Hammer presents them, Clicker questions require students to work together and pay attention to each other's opinions. This aspect of the course encourages argumentation. Also, lecture is one of the places where Hammer is most able to encourage students to think about their learning and to seek and sort out confusion. In addition to being the place where he presents much of the Physical concepts learned in the course, it is the place where Hammer can talk about learning and the most effective ways to learn Physics. Finally, lecture is the place where Hammer teaches by focusing on concepts rather than formulas. He encourages students to do the same.

Problem sets encourage students to spend time being confused and to work collaboratively

Problem sets in Physics 11 look different from those in many other science courses. Each problem set has five questions, and each question is meant to take students between a half hour and an hour to complete. Students are encouraged to work together on problem sets, and to use the questions to better understand what they do and do not yet understand.

Problem sets enforce the epistemological hallmarks of this course most notably by encouraging students to work collaboratively to find answers to difficult questions, and by forcing them to spend time being confused. Because the questions are so hard, students often spent time confused before knowing how to approach a problem. This was encouraged. Finally, Hammer tried to make his problems such that students could not be successful on them by simply using formulas. The questions require synthesis of multiple concepts or ideas from class, and are often things that students have not seen before. It is also important to note that problem sets are graded with extensive partial credit, with the goal of giving students credit for doing worthwhile, scientific thinking. Often the process of arriving at the answers to these questions is more important than the answer that students give.

Exams are a chance for students to practice the skills they've learned in class and through homework

Exams in Physics 11 are composed of two types of questions. The first is multiple-choice questions. There are eight on each exam, and they are meant to be questions that a student who has arrived at a good understanding of the material should not have trouble answering. The second is short answer questions, which are focused on students' reasoning and methods of arriving at an answer. There are three short answer questions on each exam. The last short answer question on each of Hammer's exams, Question 11, is a special type of question that requires students to argue for both sides of an explanation for a given Physical phenomenon that they have not been asked about yet in the course. The question is in three parts. The first asks students to give the explanation they think is correct. The second asks for an explanation that someone else might think is correct. The final part asks students to prove why the other person is incorrect in their thinking. Students are graded on their ability to provide a relevant, plausible counter argument, and then to meaningfully respond to that argument. As Hammer described it, "Question 11 requires thinking about a problem from multiple angles explicitly" (Personal Communication).

Exams follow from the epistemological hallmarks most explicitly in that they encourage students to start from something that they know, the questions they've practiced in class, and move through something they've never seen before, the exam questions. Hammer tries to write the exams so that people who have memorized formulas cannot succeed just based on that fact. He uses new, difficult questions and encourages students to use the ideas they understand to answer them, rather than the formulas they know. Additionally, like on problem sets, partial credit is given for the short on answers on exams to encourage student reasoning and scientific thinking.

Lab allows students to use materials to illustrate important concepts, and to practice experimentation

Lab is one of the parts of Physics 11 that *looks* most different from lab in other science courses. Students are not given a lab protocol, but instead are given a question or one-sentence assignment and are responsible for coming up with their own experiment. They work in groups of three or four, and present their experiment and their findings to the class at the end of the period. Lab reports happen in class, with much less of a focus on traditional scientific writing and much more of a focus on communicating effectively what was done and what it showed. Students have the chance in lab to develop an experiment with the help of peers, try it, and then analyze the experiments of their peers and provide feedback on other methodologies.

Lab branches most clearly from the idea of working collaboratively and using argumentation to arrive at the answer to a problem. It also encourages students to start from something they know, for example that friction exists, and work through something that they don't quite understand, for example the measurement of friction's effect on a sliding block of wood. Group work encourages students to explicitly sort out confusion together, and the creation of one's own protocol encourages the use of mathematical formulas as a tool rather than as the means of finding an answer. In contrast to labs where students are explicitly told what to do and how to do it, this lab is noticeably different in its guiding philosophy and in the practices seen within it.

Recitation and office hours give students more forums to talk about Physics

Recitation, called "Discussion section" in this course, and office hours are additional opportunities for students to talk about the learning they are doing and to sort out the confusion that they have. Discussion section is not a place where students get answers to the problem sets, but instead is a place to continue the conversation from lecture and ask additional questions in a more personal setting. Office hours are similar, and are facilitated by Dr. Hammer and the teaching assistants for the course. As another forum in which to talk about Physics learning, these practices stem from the epistemological hallmarks of the course much the same way that lecture does, encouraging the same types of thinking and learning.

Conclusion

Because of the philosophy driving the course and the specific ways that philosophy is implemented, Physics 11 is unique. It is different from other Physics courses and other introductory-level science courses at Tufts. For this reason, the course is an interesting subject of study when considering they ways that students think about learning Physics and when considering useful reforms in Physics education.

Methods

I began this study in September of 2012 by sending a recruitment email (Appendix A) to every student who had taken Physics 11 at Tufts. I received 27 responses from 191 students, which is a 14 percent response rate. I used interviews as a data collection method for this study. In other studies, several methods of data collection have been used, including interviews, pre-post surveys, and weekly journal entries (Hammer, 1994; Redish and Hammer, 2009; Lising and Elby, 2005). Interviews provide rich data on individual student experiences, and are helpful in taking into consideration a student's major, motivations for taking a course, and history as a student. Talking with students worked better for me than surveys would have, because it allowed me to ask specific questions and follow up on interesting comments that students made.

I completed fifteen interviews with a mix of students who taken the course in the spring of 2011 and the spring of 2012. Seven of the students were engineering majors, and two were completing the course as a medical school prerequisite. I interviewed nine freshmen, four sophomores, and two juniors. I spoke with each student for between twenty and forty five minutes and asked about their general experiences in Physics 11 as well as their feelings on each specific aspect of the course, which included lecture, lab, problem sets, exams, office hours, and recitation. The interviews were semi-structured, so I used a general interview protocol to ensure consistency in the data I collected. I also allowed space to ask additional questions and get the full scope of each student's experience (Appendix B).

When the interviews were complete, I listened to them several times and took notes on each question that was discussed. As I listened, I looked for trends in the data. I was interested in patterns related to student epistemologies and responses to specific course practices in the course I was studying. I met with Jessica Watkins, a post doctoral student in the Education Department at Tufts, weekly to examine these trends, check them against exact quotations in the data, and look deeper into individual students' experiences. I was able to categorize students into general categories based on whether they enjoyed or did not enjoy the course, as well as whether they understood the epistemological goals of the course. Through this categorization and data analysis, I formulated two conjectures based on my data. I developed case studies for several students whose experiences were particularly relevant to my research. I also found quotations from other students that would be used to support my claims.

To situate my work within other notable work being done in science education research, I conducted a literature review. I especially noted studies that consider students epistemologies in Physics, as well as studies that have implemented course reforms aimed at improving student learning in science.

Conjecture 1: "Getting it" and "Liking it" are associated

The first noticeable pattern in this data is that "getting" this course, or understanding the epistemological goals of various course practices, and liking the course are associated. As both "getting" and "liking" a course can be subjective determinations, it is important to unpack what each term will refer to in this data set and for this set of arguments.

For the purposes of this paper, "getting it" means understanding the "game" students are being asked to play in Physics 11 and why it is important to be playing it. Just like most games, Physics 11 has rules and general practices that are integral to success. For example, the questions on problem sets in this course are meant to be hard for students to understand and to solve and are meant to require significant time and often group discussion. A student who gets it would learn this "rule" near the beginning of the course and would expect problem sets to be like this. Maybe she would make plans to do problem sets in a group, or would allow herself more time to do each problem sets so she didn't feel rushed and frustrated. She would not expect problem sets to contain questions requiring rote skills or simple formulas. A student who gets it would also understand why problem sets are so hard; that they are meant to encourage students to practice making sense from confusion or to encourage them to work in groups and see multiple perspectives on one problem. She would understand that doing problem sets in this way is an important part of doing science.

Certain student responses were coded as signs of getting various course practices. First, students who got the course often discussed the way that Dr. Hammer focused on their intuition as a starting point for learning Physics, or how he tried to make the Physics they were learning in class intuitive. For example, when discussing intuition in the course, Kyle said, “If I’m taking Physical Chemistry, […] if you don’t get it, you’re just going to have to memorize it and memorize the equation. But for Physics if you couldn’t understand it intuitively, you couldn’t memorize your way to the answer because the questions were designed that the only path to the answers were through an intuitive, logical, “give me your reasons” approach (6:20).” Responses like this demonstrate a larger understanding of the purpose of the course, and thus are coded as getting it.

Another category of student response that was coded as “getting it” was when students discussed how the course taught them how to think, or how it made them think differently. Many students who got the course displayed answers like this, which were marked by responses like John’s, given while discussing exams in the course. “And I feel like the class was, in general, trying to teach you the style of thinking and approach to the problems, because you’d come to the test and you’d be like “I’ve never seen this problem before, but I know how I can start tackling it (12:15).” Students who mentioned the style of thinking required for success in the course were clearly thinking about their learning on a larger scale and thinking about the course in a broader sense.

Students who got the course also often discussed seeking and sorting through confusion, often with peers, as a common course practice. A common response in this vein would be similar to Dan's, given in his general comments about the course. "He thought that the way he was teaching models the way that science discovers things, where there's a confusing situation and then people get together and they argue and then they settle on something and they figure out what is actually going on (7:15)." Dan's recollection of Hammer's connecting his class to the larger world of science demonstrates that he (Dan) internalized this idea and saw its validity in the course. Most students who "got" this Physics course also understood the idea of seeking and sorting out confusion, and of using peers as a resource for coming to answers.

"Liking" Physics 11 is easier to code than "getting it," but still requires some attention to student response. Students who were coded as liking Physics 11 showed consistent enjoyment of the course throughout the interview. Generally they only showed dissatisfaction with one or two aspects, if any. Students who liked this course were able to articulate why they enjoyed specific aspects, and provided detailed answers about this. For example, one student response that was coded as truly liking Physics 11 was one that Alex gave when describing exams. "If you stopped during the test and just turned around you would see people like scratching their heads, trying to pull things together. It was funny. I liked the exams. They were fun (14:30)." He demonstrates a true enjoyment of the course here; he really did like taking the tests in Physics 11. Many of the students who were coded as liking the course expressed similar responses.

It is also important to note that many student responses that were coded as evidence for "getting it" could also be coded as evidence for liking this course. A case study will help illustrate this and each of the signs of getting and liking this course mentioned above. Additionally, the students have been organized into a table, using their pseudonyms, below:

	Got	**Didn't Get**
Liked	John Dan Alex Evan Lily Bobby Erica Kevin Kyle	
Didn't Like	Tom*	Katie Emma Emily Nick Kristen*

*Two students, Tom and Kristen, were extremely difficult to categorize based on their experiences, and will be discussed in case studies in Conjecture 2.

Case Study: Erica

Erica is a sophomore who took Physics 11 in the Spring of 2012, as a freshman. When she began the course, Erica didn't think she was "cut out" to do Physics. She took the AP course in high school and didn't enjoy it at all, despite getting a good score on the AP exam, and then came to college to give it one more chance. After taking Physics 11 with Dr. Hammer, Erica changed her mind about Physics. She is now a double major in Physics and Math.

From the very beginning of the interview, Erica showed signs of getting and liking the course. "I loved it because it was based entirely on logical thinking rather than computation (2:50).” This gets at the idea of using intuition as a place to start in this course, one of the epistemological hallmarks discussed earlier. Erica discussed how learning *why* she was doing everything she did was so much more helpful than being told to memorize a set of equations, like in AP Physics. In discussing Dr. Hammer’s goals for the course, she said “One was to ask us to challenge ourselves and the other one was to make sure we actually understood how to do it rather than what to do (9:45).” She seemed to understand that the idea was to make Physics something that students really understood at a more fundamental level, so they would understand how and why they were doing things rather than simply what to do with various problems.

Erica also demonstrated an understanding of Physics as a course that makes students think in a specific way. When I interviewed Erica, she was enrolled in Physics 12. When asked whether anything from Physics 11 had stuck with her or was helping her in her current classes, she said that she could probably still explain everything she had learned in Physics 11, but that she wasn’t sure she could explain everything she was then learning in Physics 12. She went on to say, “I think everything stuck with me but not because I’ve memorized the concepts but more because I know how to think about it if I’m confronted with a mechanics problem or an energy problem. I can go “Okay, it’s about energy, and that’s always conserved, and where do you go from there, in this situation?” And the process of thinking about what I was studying stuck with me (9:35).” This idea of learning how to think, how to correctly approach problems that leads to an answer that is sound and not simply based on a formula, was some of the main evidence of getting the course in Erica’s interview.

A majority of the evidence supporting Erica getting the course surrounded her understanding of seeking confusion as an important practice in science. When she described participating in lecture, doing problem sets, and studying for exams, Erica talked about how the goal was to find something that was really confusing and then resolve the confusion. “Our goal was to find something we didn’t understand already. Like, “We have two things colliding in space and we know what happens, but what happens if we have two things colliding in the grass? How much of the energy is dispersed? (4:30).” She also talked about her personal experience with being confused in lecture, saying, “Often times my confusion was because I made an assumption. […] I’d have to talk out loud about why I was confused to run into the problem. So I can’t remember not resolving my confusion. I can remember being confused a lot (12:46).” Later, when recommending this course to other students, Erica said, “But you need to be a little bit patient with yourself and also willing to be confused for a while before things are resolved. But then you’ll be like the master of it, so that’s good (22:00).” Erica clearly displayed evidence of understanding the link between being truly confused about something and then resolving the confusion to obtain mastery of that thing. This was further evidenced by her descriptions of how she studied for exams. “We sometimes looked over the problem sets but rarely, because if we’d already figured out the problem it’s no longer useful to us. It has to be confusing for it to be useful because otherwise we won’t be prepared for the exam (26:05).” This idea was internalized in belief and in practice for Erica; clearly she understood that finding and resolving confusion, often with a group of people, was useful to success in Physics 11.

The evidence of Erica enjoying this course was displayed throughout her interview. She described almost every aspect of the course, including exams, as fun. “Tests were fun, actually. And stressful. They were both fun and stressful (15:00)." She demonstrated an enjoyment of learning with her peers, getting to spend time on hard questions, and finally arriving at answers. At the end of the interview, Erica explained why she finally decided to major in Physics. Her answer was powerful evidence that she really enjoyed this course that it affected the way she thinks about science:

> The reason I had stopped taking Physics, after AP Physics, I was like "Maybe I'm not cut out for Physics. Maybe I'll just stick to math and not be a science major because it looks like something I'm not really cut out to do." And I wasn't sure why I thought this. I didn't get like a terrible AP score, I actually got a pretty good AP score, but I hated the process. I hated the entire exam and studying for it. I never hated a science class until then. So I was like, "Maybe this is the point where you're like "I don't actually like this subject, I should turn away from it."" And then I realized it's kind of because if you're focused on just problem solving without understanding either the philosophy behind it or why you're solving the problem, like the applications of what you're studying, then you're just studying this to answer a question that people already know the answer to, and then it's valueless. To you and to everyone else. I think that's what frustrates me about science classes, because sometimes it does really feel like that. I think you have to make the effort to think, "Well this does have applications," or "This does have an underlying philosophy that I'm just not thinking about right now. "But because we kind of thought about that throughout the entire class, at least the philosophy, not always the applications, it always felt like I was doing something worthwhile. 27:07

Because "getting" and "liking" Physics 11 require significant explanation, it would not be enough to simply say that "not getting it" and "not liking it" are just the opposites of these without providing evidence and student responses. However, it does follow logically that not getting this course means that opposite of getting it in that not getting it implies missing the epistemological goals of the course. Students who didn't get it really didn't learn the rules of the game or, more accurately, didn't understand at all why those rules made sense. They often missed what could be called "the bigger picture" and became very focused on a detail or small aspect of the course that was difficult for them. Overall, this generally led to one of two outcomes. Either these students followed the rules anyway but expressed frustration throughout their time in the course, or they chose not to follow the rules, and tried to succeed in the course using rules they had from other science courses they had taken in the past. This generally did not work for them.

A common marker of students who did not get this course was expressing dissatisfaction with the seemingly little use of Calculus that was used in the course, or with the seemingly simple problems that did not require math. Because Physics 11 is traditionally Calculus based, some students expected a heavy focus on the Calculus behind the Physics, which to them seemed to mean a heavy reliance on the use of formulas to solve problems. In Physics 11, students were encouraged to use math, but to do so as an expression of ideas that they understood conceptually. Some students wished that the use of math had been approached differently, and cited this as a shortcoming of Physics 11. For example, Katie, a sophomore Chemical Engineer, said, " Instead of using the math to help you understand it, he would just show you the math and then tell you the conceptual way, which I didn't necessarily like (5:30). It seemed that Hammer's intention in this situation would have been to have students see how the math was connected to the concepts he was striving for students to understand, but that Katie didn't understand that. She had an idea of how much math should be involved in the course, and this course did not meet those standards.

Another common remark of students coded as not getting the course was a great deal of concern about "the right answer." Many lectures in the course involved Clicker questions that led to an extensive whole-class argument. The goal of these arguments was to allow students to reason through both sides of a question and to arrive at the answer through logical thinking. Many students who didn't get the course became incredibly focused on being told the right answer as a way of confirming their thinking or instead of coming to it on their own. For example, Emily, a sophomore Chemical Engineer, would not recommend the course to other students unless they could hold on to their own answers without getting confused by others'. "I would say don't do it unless you have a good basis in Physics. I would say make sure in lectures you get the right answers afterwards and you don't let what other people who thought A was right confuse you and just like block that out. Because by the time the test comes you don't know if that one guy who talked for like a half an hour each class was actually right or not (29:00)." She also expressed frustration with the time in the course was "wasted" on discussing wrong answers. "It was just like "how did we waste so much time with these guys in the back defending choice A when it was completely wrong? Like how could we spend so much time with someone saying that the wrong answer was right? That was just so frustrating (30:00)." Emily did not see the value in using argument to come to conceptual understanding; she and many of the students who were coded as "not getting it" were focused on finding the right answer and were often frustrated by the path taken to get there.

Additionally, students who did not get this course were often confused or frustrated by the "lack of structure in the course." Many aspects of the course left plenty of space for student discussions or student opinions, but some students were looking for structure in the form of official laboratory protocols, lots of lecture slides, a heavy textbook, or longer problem sets. For example, Emma, a junior Clinical Psychology major, said "I like doing a lot of problem sets, assigned readings, problem sets, assigned readings, because that would help me learn. […] I think just like more problem sets (16:00)." She said she was used to her science classes being more structured, and thought that having more structure in Physics would have made her much more successful in the course. This was a common sentiment in students who were coded as not getting this course.

Just as students coded as liking the course liked most aspects of the course, students who were coded as not liking it expressed dissatisfaction with most aspects of the course. They could generally articulate why they didn't like the course and how the practices they did not like related to their experiences or their learning. For example, Kristen, a sophomore Biochemistry major, said of the textbook, "I didn't like the book we had, you know, we had a little small book. It was like that thick for a semester of Physics. And we had the videos that we watched before class, and it said the exact same thing in the book that we had. […] What would have been nice was if we had a book that went into more detail. It was very brief, that we had, and I felt like it could have been explained more thoroughly or had more examples (29:00). Kristen expressed distaste with this and almost all other aspects of the course, as did most students who were coded as not liking it.

As with students who got and liked this course, it can be easier to visualize all of these principles with a case study.

<u>Case Study: Nick</u>

Nick is a sophomore who took Physics 11 in the Spring of 2012, as a freshman. He took AP Physics in high school and really enjoyed it, but had to take Physics in college as a requirement for his Chemical Engineering major. Despite enjoying Physics in high school, Nick did not enjoy Dr. Hammer's class. He was coded as not getting or liking the course, as was demonstrated in his responses to almost every interview question.

Nick showed evidence of not getting most, if not all, of the epistemological hallmarks of Physics 11. For example, in the beginning of the lecture, he discussed his frustration with

Hammer's strategy of encouraging students to explain concepts like they would explain them to an 8th grader. This was a common course practice, and was used to encourage students to stop focusing on complicated formulas and return to the basic scientific concepts behind each problem. " I'm not an eighth grader. So you don't need to explain it to me like an eighth grader because I can understand more than an eighth grader. Yeah I get it simplification is the best way to make things clear, but I don't think that that's necessary in a college setting […] I want you to explain it to me the way it's meant to be explained […] I really didn't like that (6:40)." Even though he said he "got it," he clearly did not understand why such a strategy was being used in a college setting.

Nick also did not seem to understand the idea that constructing knowledge with peers and using argumentation to arrive at a correct answer could be a useful practice in a college Physics course. He described how his high school Physics class worked, and how he really wished Physics 11 used a more substantial text book so that he wouldn't have to rely on his classmates to help him develop answers. "It [high school Physics] was more based on a book, which, you can't have inconsistencies on paper, that pass by most people. Whereas if I'm speaking to somebody and I say some non sequitur, it's sort of, it has a chance of being not really understood. What I'm trying to say is that I feel like it's more clearly explained when it's taught based on a book rather than when it's taught based on a lecture thought of by David Hammer (10:35)." Nick did not see the value in arguing; he wanted a book that would tell him the correct answers so he could go over them "seventeen times" until he understood them.

Most of Nick's "not getting it" in this course surrounded his ideas about structure. Nick expressed frustration with this aspect of almost every course practice. For example, when discussing lab, Nick said, "I am not the person who's supposed to come up with course curriculum. I am in this class because I want you to teach me, you know? If I'm going to learn, I want you to teach me. I don't want to teach myself. Because there was no book, there were David Hammer's explanations, and there was myself, and that was it for learning the course material. So overall I felt like I learned little to nothing in the class (20:07)." Nick described Hammer's lectures as untraditional and not concrete or objective, and said that he likes it much better when science is "concrete and objective." Clearly Nick did not see the point of leaving room for students to create the structure of the course; he felt that he needed more structure in order to learn successfully.

Nick really did not enjoy Physics 11; he did not like lecture, lab, problem sets, recitation, or exams. When asked whether he would recommend the course, Nick said, "Absolutely not, if they don't have to take it. Don't take it. If you don't have to learn it, don't take a class that's difficult. Take an easy class. Because you want to focus on the classes you have to take, the classes that you've decided to take, your majors. So why take Physics 11? (27:44)" When asked about students who have to take Physics as a requirement, Nick said, "I'd recommend it with anyone but him (28:00)." It seems clear from these feelings and Nick's other responses that he did not like this course at all.

What is important about these case studies as well as the student answers cited earlier is not that some students got the course while others did not, or that there was variance in whether students enjoyed the course, but rather that some experiences tended to happen together for students. Students who liked the course generally also understood the point of the course. For Erica, feeling that she was doing something worthwhile in Physics made her enjoy it so much more than she enjoyed her Physics courses in the past.

Contrastingly, students who did not understand the epistemological hallmarks also really did not enjoy the course. For Nick, not understanding why David Hammer always asked him to explain things as though he were talking to an 8^{th} grader made him feel frustrated and condescended to. Responses about students' enjoyment level in the course and their understandings of the epistemological hallmarks of the course often came together, in the same comment or the same paragraph, and were often associated in this way. Whether this is a correlation or a causal relationship is unclear at this time, but it is important to note this pattern in the data.

Conjecture 2: Beneath general categorization, more specific variability in epistemologies exists

Most students who were interviewed could be classified as getting Physics 11, which became associated with liking the course in the previous section, or not getting it, which was associated with disliking it. This means that many students seemed to hold one *type* of epistemology most of the time; epistemologies in line with the goals of the course, or those that were in some way counter to those goals. However, certain students' responses were so variable that it was difficult to classify them as either getting or not getting the course. Further analysis of these students and all of the students who were interviewed revealed a second conjecture: Students' epistemologies in response to this course were often variable on a level that was more specific than the general categorization they were given previously. That general categorization holds, but this variability exists on a more zoomed-in level. For example, as is described in one of the following case studies, one student was categorized as getting the course, and really seemed to hold productive epistemologies when describing most aspects of the course. However, his response to lab seemed to run counter to those epistemologies. Noting this variability is important; students cannot be classified into a binary without considering the parts of their experiences that fall outside of it. For some students, this variability impeded such classification; those students are described here, as is Tom, the student mentioned earlier.

In each of these case studies, evidence is given for the student getting and not getting the course using evidence from his or her responses to lecture, lab, homework, exams, and discussion section. The possible causes of this variability will be considered later in this paper.

Case Study: Kristen

Kristen is a sophomore Biochemistry major who took Physics in Spring of 2012, as a freshman. She took the course because it is required for her major and because she did not get into the English class she was hoping to take that semester. The majority of Kristen's responses suggested that she did not like and did not get the course. However, some of Kristen's comments indicated that she might have understood some of the epistemological goals of Physics 11, which was confusing given her other answers. Analyzing Kristen's experiences in depth helped highlight some of the patterns in her responses, and pointed to why they might occur.

For most of the interview, Kristen did not seem to get the course. For example, Kristen did not seem to "get" the point of using Clicker questions during lecture. She started out by saying that she really enjoyed the use of Clickers, but then went on to give some responses that indicated that she might not have actually enjoyed them the whole time. In response to her comment about how some questions took 30 minutes or more to discuss, I asked if she thought that was too long to spend on one question. She said she did, because, "it didn't give him enough time to discuss other things." She went on to say, "And a lot of time the questions that took longer to explain were the ones that got really confusing and then I didn't quite understand at the end, what was happening[…] And I just kind of felt like it was up in the air and then maybe if I just missed the answer for a quick second, he said something and I didn't really quite get it or understand it, I was just lost (10:25)." Kristen's focus on getting the "right answer" and potentially "missing it" suggested that she wasn't using the Clickers to understand, but rather to get the right answer to as many questions as were asked. Kristen's answers indicate that she didn't really like or get the use of Clickers during lecture.

Kristen's responses to problem sets and exam questions indicated that she also did not get this aspect of the course. In talking about problem sets, she said, "You had to devote at least half an hour to an hour per question. And, I didn't really like that that much, not necessarily because of the time commitment but it's just a lot of concepts squished into one question, or just one concept that you may not necessarily understand that well (24:00)." She went on to say that she prefers having smaller questions rather than bigger questions that involve many concepts. She did not seem to see the value of using problem sets to connect concepts or to encourage students to work collaboratively to find answers. In speaking about exams and assessment, Kristen talked about how she did not like that students could get credit for wrong answers in the course. "[…] you can get credit if you have an argument and you can back it up legitimately, even though it's not right, it could still, be right. And I thought that caused, especially with me, a lot of confusion because I was never really sure what *was* right and what wasn't right and it bugged me a little bit (35:05)." Kristen's idea of science seemed to be one involving a right answer, for which students should get credit, and any number of wrong answers, for which they should not.

For Kristen, it seemed important to be told what the right answer on exams was, because that would benefit her most in the long term. She did not see the value of getting credit for the process of getting to an answer, regardless of whether that answer was correct or incorrect.

As evidenced by her comments about Clickers, problem sets, and grading, Kristen did not really get it or like this course. However, when describing certain course practices, like lecture and exams, she really seemed to understand the epistemological goals of the course. For example, when talking about lecture, Kristen mentioned how demonstrations were really helpful because they helped resolve inconsistencies between intuition and reality. "[…] if say the textbook tells you, say, "this is what happens," and in your head you're thinking, "Really? That doesn't really make sense." But if you actually see it happening in front of you, it was kind of a crazy thing to think about, then you saw it too (29:52)." She seemed to really enjoy this aspect of the course, and to understand the epistemological goals behind it. Demonstrations were used to help students wrestle with the tension between what they think happens and what actually happens, and Kristen understood that.

When she commented on exam structure, Kristen seemed to understand the epistemological goals as well. "It was just the way he asked questions, you know? In class he would always say, "What do you think about this? Does anybody else think differently?" So it was just kind of that kind of thinking […] so the test questions were like that. It was kind of what you would expect from lecture, questions he would ask in lecture. So it's […] kind of weird to think about what somebody else would say after you already had your answer (15:23)." Here Kristen seemed to understand that one of the main goals of Physics

11 is to have students focus on argumentation and reconciling reality with intuition. She did not seem confused about the structure of exams at all. Additionally, in discussing Question Eleven, she said, "I think it's his whole idea about us trying to understand things and looking at things from different points of view. It was a very big thing in the class (15:23)." This seemed like an authentic answer from Kristen, and showed that she was thinking accurately about the goals behind that course practice.

Finally, when Kristen talked about problem sets, she said " […] he told us that he taught the course so that we wouldn't just sit down and memorize everything, and that he wanted us to create an understanding of the course, so we're not just looking at equations and plugging numbers in and spitting them back on. But, you know, to look at something, and then we understand what's going on, and then we'll know what to do (22:50)." In instances like this, it seems like Kristen understood the epistemological goals of problem sets and of the course. She knew that to succeed in this course, it was helpful for students to be able to work collaboratively, and she seemed okay with that idea.

Kristen's case is a confusing one. At many times in the interview, it was unclear whether she liked or disliked, got or didn't get the part of the course that she was discussing. It is possible that she was just repeating things that Dr. Hammer had said during class, things that she thought I, as an interviewer, wanted to hear. It is also possible that different parts of the course led Kristen to have different epistemological stances. Regardless, her experiences prove that though students can be generally categorized with respect to how much they understood the epistemological hallmarks of this class, significant variability can occur within each student.

Case Study: Tom

Tom is a sophomore who took Physics 11 in the Spring of 2012, as a freshman. He took the course as a medical school prerequisite. Tom's reactions to the course were difficult to classify; he seemed to "get" some parts of the course, but he really missed the goals of some other parts. Classifying his experience was difficult given the variability of his answers.

In about half of Tom's answers during the interview, he seemed to really like and get the course. For example, when speaking about lecture, he spoke about using many peoples' opinions to solve problems, and about using common sense as an approach to problem solving. "[…] he would just leave a problem on the board, that would connect a bunch of different kinds of equations, and we would just go through it. Kind of we would talk our way through problems, and it wasn't things you could do just with simple math. It took a lot of people's opinions to solve the problem. And by doing so, you would learn a whole bunch of different ideas, but it wasn't like a lecture at all (4:30)" Tom seemed to understand here that understanding others' thoughts and ideas can be helpful in arriving at answers and in learning to see problems from many angles. He seemed to get this aspect of the course and, for the most part, to enjoy it as well.

Tom's responses to lab also suggested that he liked and got this course. When asked about his experiences in lab, his initial response was telling:

> This is what I agree that Physics did a better job of, because in Chem labs, or Bio labs even, they pretty much just tell you what to do, you can ask the TA "Yo, I don't understand this step, can you tell me how to do it" and they'll just walk you through it... But Physics they would just give you any question and be like "alright, do the best of your ability to solve it. Do the best of your ability to use these materials to like find the approximate acceleration and gravity. So I think that was beneficial, because we had to talk, and there were like a hundred different ways we could solve It. We could be creative in our own ways, knowing what we know. I feel like it was a

> real world application of class, which was the most beneficial, because it wasn't problems that were too much of a stretch, but they still tested our mind in different ways to do all of them (17:17).

Tom discussed here how being creative in lab was useful, and how using different people's ideas helped his group arrive at good procedures. He rates the lab more highly than the ones he took for Chemistry because there was a lot more creativity and original thinking, which suggests that he sees the benefits in these types of thinking. Tom went on to say that Physics lab was a place where people had to really talk through problems, which was helpful "for real life and for learning Physics." All of his comments about lab were consistent in showing that he got it, and that he enjoyed it too.

Despite several responses coded as strong evidence for liking and getting this course, some of Tom's later answers confounded this evidence in suggesting that he did not like or get the course. When speaking about problem sets, Tom didn't seem to enjoy or understand the epistemological goals of this aspect of the course. He was very focused on the fact that the no one in the class, or no one that he knew, was able to complete the problem sets alone. It always required group work. For Tom, this made problem sets "too difficult" and not enjoyable. "It wasn't a level of problem set that you could just do on your own. Like I feel like everyone I asked would have to look it over between like five other people, but it was just too difficult […] even with your notes […] I feel like for the actual class, compared to the test, they were just too much of a stretch (15:00)." When asked if Dr. Hammer encouraged students to work together on problem sets, Tom didn't remember whether this behavior was encouraged. He seemed to miss part of the "point" of problem sets, a point he seemed to get in lab, which is that using others' opinions to solve problems can be useful in arriving at correct answers.

Tom's feelings about exams were some of the first that he shared, and he seemed to not like them at all. "I feel like it wasn't a fair correlation of your grade […] if you looked at the kids who took tests and their grades, it wasn't a direct correlation of how well they knew Physics (4:00)." Tom returned to this point later in the interview, saying, "And I didn't put in that much effort and got like a B+ and my friend put in like a ton of effort and got a C+ (20:31)." Here Tom expressed the idea that assessment in the course was not fair, and that effort was not directly correlated to success in the course. This is counter to the philosophy expressed by Hammer during lecture, and to the grading style of the course, in which students could get partial credit on almost all parts of the course for making an honest effort and reasoning logically. Tom also says that Hammer didn't give students enough information to study for tests, and that it was his only class where he found himself looking up "Physics YouTube videos" or other outside sources of information to study. It seems that using YouTube videos is another way of considering others' thoughts when developing your own, and a practice that might have been praised by Hammer. However, Tom saw it as a failing of the course. It seemed clear that he did not enjoy the exams in this course, but also that he didn't really understand the epistemological goals behind them.

Like Kristen's experiences in this course, Tom's were confusing. At some points, he clearly articulated course goals and seemed to really "get it." At other points, he did not seem to understand the epistemological goals of the course, or seemed to hold an epistemology that was counter to one he has expressed at a different point in the interview. For example, when speaking about lab, Tom was excited about working with his lab partners to talk through a problem and figure out the answer. However, when speaking about problem sets, Tom wished that the problems were easier, so he could do them on his own. Tom's epistemologies, his ideas about learning Physics, were variable. Even though he could perhaps be generally classified, this variability is significant and should be considered.

Case Study: Dan

Dan is a senior who took the course in the spring of 2011, as a sophomore. He took the course as a requirement for his Chemistry major. Dan seemed to like and get the vast majority of this course. However, his responses to one portion of the course seemed not to follow from his other responses, suggesting that perhaps his epistemologies are more variable than one might expect.

For almost the entire interview, Dan seemed to like and get Physics 11. In his initial description of the course, he called it, "the most human approach to science I've ever experienced" (2:10). When speaking generally about Hammer's teaching methods, he said, "He thought that the way he was teaching models the way that science discovers things, where there's a confusing situation, and then people get together and they argue and they settle on something and they figure out what is actually going on" (7:15). Both of these comments suggest that Dan liked the course, and they are also evidence for his getting it. He seemed to really see the overall picture of the course when speaking generally about it, and his experiences with specific experiences supported these first comments.

Dan's response to the use of Clickers during lecture was another indication of his liking and getting the course. "I think that that kind of filter between people and audience is really integral to get everybody to participate. You know, not everybody is going to stand up in front of the class and explain what they think or say their thinking, but everybody feels safe with having an electronic anonymity […] And sometimes it was really dramatic where you got an initial impression and then somebody just said something in the class and reminded somebody of one of the ways that we learned and one of the ways you can think about it and then all of a sudden the histogram totally shifts to another answer" (12:00). When he mentioned "electronic anonymity," he seemed to understand not just how the Clickers were useful for his understanding but how they could be useful for all of his classmates as well. Then, in talking about the "dramatic shifts" that sometimes happened during class, he seemed to see the effect and usefulness of using many people's opinions to arrive at answers to problems.

Dan's responses to exams were also evidence that he liked and got the course. In speaking with Professor Hammer about the goal of exams, he said that he tried to write them so that if students had been paying attention in class all along, they would be able to succeed on exams without much trouble. Dan's responses seemed to confirm that this did work for some students. "I never studied for that course. It matched the way that I think and I learn, so just being very engaged during the class and doing the pre-class activities was completely sufficient to my learning. I never studied once for that course" (10:24). Dan was engaged with the course throughout, so studying was not difficult for him. In his actions, he seemed to "get" the goals of the course and the exams, and also enjoyed the success he experienced.

With so much evidence that Dan got and liked this course, it is surprising that he seemed not to get or like lab. "I was frustrated in lab. I guess it was, again, trying to challenge the conventional way that we wrote things, but it was slightly disconnected from the course […] I've taken many other labs that were far, far less related, but there was so much put upon uncertainty in measurements and different kind of things that weren't helping us in a test situation with critical thinking so much as with high attention to detail. Not that those aren't important skills, it just wasn't playing to the same skill set." (16:10). Dan seemed to think that the lab was developing his skills in attention to detail more than in critical thinking, which is really the opposite of what this section of the course was attempting to do. The broad question and concept-focused lab write-ups were meant to allow students to focus on what they were actually doing rather than how they were writing about it. To Dan, this seemed to feel like students just had to pay more attention to detail, because there was no protocol for him to follow.

He went on to talk about how it felt to work in groups and to work on a question collaboratively instead of following a detailed protocol.

> I appreciate the process of self-discovery, but [...] for each experiment or question there was a methodology we were supposed to employ. So it mostly felt like, "Okay, can we just get at what you're trying to get us to do instead of actually brainstorming and being creative with one another?" [...] I'd rather for a lab course to be organized. I think that's more similar to a real lab experience. [...] I just don't think that people do science in their garages. I don't think that that kind of collaborative problem solving was really useful to anything (18:00).

Dan's comment that "people don't do science in their garages" reveals something about the way he thinks about science. For Dan, science seems to be something that happens in a lab, with a specific protocol, with supervision and guidance. Indeed, he went on to say most of this in his interview. Science seems not to be something that is constructed in response to a given question or an observed phenomenon. In contrast to his ideas from earlier in the course, where he praises Clickers because they help students to work collaboratively and arrive at an answer, or calls Hammer's approach "Socratic," and "human," these answers are surprising. Dan's epistemologies also seem to be variable; his ideas about learning Physics seem to be different in different aspects of the course.

Conclusion

All three of these case studies are stories of students who seemed to have varied epistemologies about science learning, which became apparent during their interviews. For Kristen, Tom, and Dan, during some parts of the course they really seemed to get it, while others showed that they weren't thinking the same way that Hammer was when he planned the course. These students could be generally classified based on their comments into groups of students who got or didn't get, liked or didn't like this course. However, the variability is also important to note; these students', and some other students', ideas about learning Physics seemed to shift during parts of their interview, depending on which aspect of the course they were discussing.

In addition to noting this variability, it would be interesting to classify it further and perhaps determine the causes behind it. For example, why does one student mentioned here get lecture and not get lab, while another had the opposite experience? It is impossible given the information gathered in this study to make claims about the causes of variability in student epistemologies in Physics 11. However, some of the data lends support to two different hypotheses, both of which will be explained in the next section.

Suggestions for Future Research

There were some patterns in this data that would be interesting to research further, and that could lead to additional frameworks or other ways of classifying students' experiences or epistemologies in this course.

Hypothesis 1: Epistemologies are affected by external support

One hypothesis about variability in student epistemologies is that students' epistemologies are influenced by the external support they receive from their professor or teaching assistants. Students taking Physics 11 receive different amounts of coaching during different aspects of the course. In lecture, for example, students receive a great deal of coaching from Professor Hammer. He intersperses comments about his philosophy of teaching and the best ways to "do Physics" throughout each class, and he gives students support for doing this kind of thinking. For example, Hammer often stresses the importance of being able to explain ideas in simple terms ("Could you explain it to an eighth grader?"), and responding to counter arguments (Hammer 2012). Students also receive coaching from their TAs in lab, though the consistency of this support cannot be verified without more extensive study. When studying for exams or working on problem sets, students receive the least coaching and support. These are the times when students are left to use the thinking they've been practicing in class.

By this hypothesis, it would be expected that many students would be most likely to display epistemologies focused on sense-making, seeking and sorting out confusion, and working collaboratively to arrive at answers to problems when discussing lecture. They would be slightly less likely to do when commenting on lab. When discussing exams and problem sets, these students would be the least likely to hold these types of epistemologies.

For Tom, a student discussed earlier, this framework seems to hold. When talking about lecture, he noted how useful it was to consider many students' opinions when solving a problem. Similarly, in lab, he talked about how TAs did not just give out answers, and how much creativity went into the development of his group's laboratory procedures. He seemed to hold epistemologies focused on creativity in science and collaborative sense-making. When talking about problem sets and exams, however, Tom seemed to have different epistemologies. He was frustrated with problem sets because they were "too difficult" to be completed on his own, or to be enjoyable. Discussing exams, he said that he felt like there was not a direct correlation between effort and the grades that students received, despite the extensive partial-credit grading system used by Hammer and the teaching assistants in the course. Tom's epistemologies regarding these parts of the course were focused on working individually rather than collaboratively, and he did not seem to "get" the point of the grading system on exams.

It would be interesting to further investigate the effect of coaching on student epistemologies. Are all students like Tom, best able to practice sense-making and collaborative learning when being explicitly coached during lecture? If so, is it possible to change course practices to encourage students to do this type of learning during all aspects of the course?

Hypothesis 2: Epistemologies are affected by proximity of grades

Another hypothesis is that student epistemologies are affected by the felt proximity to grades in each part of the course. This hypothesis maintains that when students feel the pressure of their grade in the course, as well as the pressure of how this one course will affect their college trajectories, they are more likely to resort to epistemologies they've held in other courses, which might be the opposite of those Hammer was trying to develop in this course.

Students experience varied levels of grade pressure in this course. In lecture, students are graded on very little of their experience. They receive participation points for using their Clickers, but this has only a small impact on their final grades. In lab, worth fifteen percent of the course, students feel slightly more pressure from their grade. Exams and problem sets, collectively worth seventy percent of a student's grade, exert the most pressure on students in terms of performance.

During their interviews, many students commented on the ways that their grades affected the way they worked in the course. For example, Kristen, one of the students studied earlier, commented on exams and problem sets. She did not like having only five questions on problem sets because there was too much "squished into one question," and noted that she would have preferred to have lots of smaller questions first, followed by some larger ones. This could be because only having five questions makes it harder to get a good grade on problem sets if a student "didn't necessarily understand" one concept. Similarly, her frustration about getting partial credit for wrong answers on exams suggests an epistemology focused on the usefulness of getting right answers and good grades for those right answers, not being graded on the process of arriving at an answer. This course challenged Kristen's ideas about how students are graded, and when she felt the pressure of her grade, she seemed to hold very different epistemologies than when she didn't.

Nick, a sophomore Chemical Engineer, commented on his experience in lab, expressing frustration with the way it was graded. "You should allow us to work on it outside of class, or you should put less weight in the lab, so that if I do badly on the lab it won't affect my grade. […] For me, that class wasn't about learning Physics, it was about getting an A. I had learned Physics before, and I had to take that class, so the only reason I took the class was to get an A (17:40-18:55)." Nick expressed the idea that if the lab had been worth less of his grade, he would have been much more comfortable trying it out the way that Hammer proposed, which was different from the way he had experienced it in the past. This was one of several student experiences in which grade pressure got in the way of experimenting with new ways of thinking about or doing Physics.

By contrast, very few students commented on their grade when speaking about lecture, likely because there is very little grading pressure in lecture. Some students commented on missing the "right answer" on Clicker questions, but these comments seemed to suggest that students were thinking ahead to exams, when they would need the right answers to study, not that they were concerned with how their grade for Clicker questions would affect their total grade. Indeed, students were only graded for participation using the Clickers, not whether or not they answered correctly with them.

It would be interesting to more explicitly study the way that grades affect student epistemologies in this course. From the limited evidence here, it is possible to see that grades can get in the way of students' being willing to experiment with new ways of doing or thinking about Physics. If this is a consistent trend with students who take this course, is it possible to adjust course practices to make them more conducive to student learning? If lecture is the place where students are most able to take risks in their thinking about Physics, how can these lower-risk settings be created in other parts of the course? It would also be interesting to think about how this course's ideas about grades and learning fit into the larger Tufts grading culture. Is it possible to help students think less about their grade if they are receiving a great deal of pressure about it in their other classes?

Conclusion

The questions that have been raised in this section could be the groundwork for future studies, and could lead to additional frameworks to be used to categorize student experiences in Physics 11, or in learning Physics in general. It would be useful to do a study that follows students throughout their experience in the course and focuses on the grade pressure they experience and how that affects their openness to new ways of thinking and learning, or on the coaching they experience and how that coaching affects their epistemologies.

Discussion

Through this project, I did meaningful learning about student epistemologies and current reforms in university-level science education. In the beginning of this paper, I defined my goals as hoping to learn about current movements in science education reform, tap into conversations happening at Tufts on this subject, and investigate a reformed course and they ways it was encouraging students to think. Through my literature review and data collection, I was able to situate myself within current research and within conversations on Tufts campus. In analyzing my conversations with students, I was able to make two data based claims about student epistemologies and suggest directions for future research.

In literature review, I noted the fact that this study is unique because it investigates student experiences through interviews conducted between four and sixteen months *after* the course of study was completed. I think it is important to consider this context in the analysis of the aforementioned conjectures. Students who understood the epistemological goals of Physics 11 did so even after they had taken at least one summer away from it. Students who did not might have seemed like they did right after the course was over, or might not have ever understood the goals of the course. It would be interesting to investigate student epistemologies during this course, immediately afterwards, and several months afterwards. This would provide interesting insight into the stability of student epistemologies, and into the ways that this course fits into the science culture at Tufts.

In addition to the “content” that I learned through my research, I also learned about the process of doing research in education. This year long endeavor has taught me what it means to apply for IRB approval, conduct interviews with students, transcribe and analyze data, research relevant literature, seek guidance regularly, motivate myself to do completely independent work, and write in a way that is both clear and thought provoking. I am confident that these are skills that will benefit me in future research endeavors or teaching efforts, as I now feel more informed about current developments in the field of science learning.

I hope that my work will generate conversation among science faculty and potentially among students about what it means to “do science” at Tufts. I am proud to attend a university that takes note of meaningful research and student needs and makes changes as a result. I am excited about the types of change that have already started happening in science courses on this campus, and I hope that this study will contribute in a small way to the larger conversation.

Appendix

A. Recruitment Email (sent to all Physics 11 students):

Dear Physics 11 student,

My name is Mary Sypek, and I am a fellow Tufts undergraduate majoring in Biology and Child Development and minoring in Education. I am writing to you because you were enrolled in Dr. David Hammer's Physics 11 course (General Physics I) sometime in the past two years. I am conducting a research study this year that will analyze student experiences in this specific course and how they reflect student attitudes about science and science learning. Because of research protocols, you must be OVER 18 years old to participate. If you meet the age requirement, I would like to ask you to participate in this study.

Your participation in this study will involve one interview with me, during which we will discuss your experiences in Dr. Hammer's class and other experiences with science courses at Tufts. The interview will take place ideally within the next few weeks, and will not last more than one hour. It's possible that a follow-up interview will be necessary, and if so, I'll ask you to schedule one. You will be compensated for this interview and can decline it if you choose. Additionally, you will be given the option of allowing me to view your coursework (tests, assignments, labs, and projects) from this class as data for this study. Your participation as well as your responses to interview questions will remain anonymous to Dr. Hammer and all other professors and faculty. The consent form for the study is attached to this email.

If you participate in this study, you will receive $15 for each hour that you participate. If you are interested in participating, please respond to me at mary.sypek@tufts.edu, and I would be happy to set up a time for our interview. You do not need to sign or bring the consent form to the first interview; I will have copies available at that time for you to sign. Thank you so much for your help with this project; I look forward to hearing from you.

Best,
Mary Sypek
Tufts Class of 2013
Child Development and Biology

B. Basic Interview Protocol

General Questions:

First of all, thanks so much for meeting with me. As you probably read in the email and consent form, I'm a Bio and Child Development major, and I'm really interested in how students learn about science, how they view science classes, and the kind of role that science can play in students' lives as a result of taking science classes. David is also interested in all of that and has focused a lot of attention on bettering teaching practices based on how students learn. I'm a Bio and Child Development major, and these interviews will eventually help me with my senior thesis, which is going to about science learning at the university level.

So to start, tell me a little bit about yourself. What are you majoring in?

As you know, the course I'm really focusing on is Physics 11. To start, I'd really like to hear anything you have to say about the class. What did you think of it?

So I'm really interested in whether anything from this class "stuck with you" after you finished it. Is there anything that you really remember or use, or have your views or ways of thinking changed at all since taking the class? Or is it kind of just "done" for you?

If my roommate were thinking about taking this class, what would you tell her about it?

How'd you do in the class?

Some specific aspects (to be touched on at some point):

Lab
- What does a typical day in lab consist of?
- Do you feel as though lab goes along with lecture and recitation, or is more of a separate experience?

Recitation
- Was recitation optional? Did you go?
- Did you find recitation to be helpful?

Office Hours
- Did you go to office hours? How often?
- What kinds of things did you do in office hours?
- Did you find them to be helpful?

Assessment
- What was a typical test like?
- How did grading in the class feel for you?

Typical day in class
- What kinds of things did you do each day in class?
- I noticed that David often used clickers. How did that feel for you?
- How did the structure of class feel for you? Did you feel like it flowed in an understandable way, or did it feel disorganized?

What was different from other classes?

References:

Beichner, R., & Saul, J. (2003). Introduction to the SCALE-UP (student-centered activities for large enrollment undergraduate programs) project. *Proceedings of the International School of Physics,* (July), 1–17.

Chabay, R., & Sherwood, B. (2006). Restructuring the introductory electricity and magnetism course. *American Journal of Physics*, *74*(4), 329-336.

Crouch, C. & Mazur, E. (2001). Peer Instruction: Ten years of experience and results. *American Journal of Physics*, *69*(9), 970–977.

Elby, A. (2011). Getting started with research on epistemologies and expectations. In C. Henderson & K.A. Harper (Eds.), *Reviews in PER, 3*, 1-33.

Etkina, E., & Heuvelen, A. (2001). Investigative science learning environment: Using the processes of science and cognitive strategies to learn physics. *Research-Based Reform of University Physics*..

Ford, M. (2005). The Game, the Pieces, and the Players: Generative Resources from Two Instructional Portrayals of Experimentation. *The Journal of the Learning Sciences* ,14 (4), 449-487.

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction*, *12*(2), 151–183.

Hammer, D., & Elby, A. (2002). On the form of a personal epistemology. In B. K. Hofer & P. R. Pintrich (Eds.), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (Mahwah, NJ: Erlbaum), 169-190.

Hammer, D. (2012). Challenges and possibilities of meaningful assessment in large lecture introductory physics. “Background Research Paper No. 40” for the National Study of Education in Undergraduate Science, University of Alabama, Tuscaloosa.

Hammer, D. (2012). Physics 11 Syllabus. *Tufts University*, Print.

Hammer, D. (2013). Personal communication. 8 March.

Hofer, B. K., & Pintrich, P. R. (1997). The Development of Epistemological Theories: Beliefs About Knowledge and Knowing and Their Relation to Learning. *Review of Educational Research*, *67*(1), 88–140.

Leach, J., Millar, R., Ryder, J., & Séré, M.-G. (2000). *Epistemological understanding in science learning: the consistency of representations across contexts*, 10, 497–527.

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics*, *73*(4), 372–382.

May, D. B., & Etkina, E. (2002). College physics students' epistemological self-reflection and its relationship to conceptual learning. *American Journal of Physics*, *70*(12), 1249-1258.

Perry, W. G. (1970). *Forms of intellectual and ethical development in the college years; a scheme*. New York: Holt, Rinehart and Winston.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology*, *84*(4), 435–443.

Redish, E. F., & Hammer, D. (2009). Reinventing college physics for biologists: Explicating an epistemological curriculum. *American Journal of Physics*, *77*(7), 629-642.

.