A dissertation

entitled

Improving Student Learning and Views of Physics in a Large Enrollment Introductory Physics Class

by

Kathy J. Shan

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy Degree in Curriculum and Instruction

_____
Dr. Rebecca Schneider, Committee Chair

_____
Dr. Mark Templin, Committee Member

_____
Dr. Charlene M. Czerniak, Committee Member

_____
Dr. Karen Bjorkman, Committee Member

_____
Dr. Patricia Komuniecki, Dean
College of Graduate Studies

The University of Toledo

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An Abstract of

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Introductory physics courses often serve as gatekeepers for many scientific and engineering programs and, increasingly, colleges are relying on large, lecture formats for these courses. Many students, however, leave having learned very little physics and with poor views of the subject. In interactive engagement (IE), classroom activities encourage students to engage with each other and with physics concepts and to be actively involved in their own learning. These methods have been shown to be effective in introductory physics classes with small group recitations. This study examined student learning and views of physics in a large enrollment course that included IE methods with no separate, small-group recitations. In this study, a large, lecture-based course included activities that had students explaining their reasoning both verbally and in writing, revise their ideas about physics concepts, and apply their reasoning to various problems. The questions addressed were: (a) What do students learn about physics concepts and how does student learning in this course compare to that reported in the literature for students in a traditional course?, (b) Do students' views of physics change and how do students' views of physics compare to that reported in the literature for students in a traditional

course?, and (c) Which of the instructional strategies contribute to student learning in this course? Data included: pre-post administration of the Force Concept Inventory (FCI), classroom exams during the term, pre-post administration of the Colorado Learning Attitudes About Science Survey (CLASS), and student work, interviews, and open-ended surveys. The average normalized gain (<g>=0.32) on the FCI falls within the medium-gain range as reported in the physics education literature, even though the average pre-test score was very low (30%) and this was the instructor's first implementation of IE methods. Students' views of physics remained relatively unchanged by instruction. Findings also indicate that the interaction of the instructional strategies together contributed to student learning. Based on these results, IE methods should be adopted in introductory physics classes, particularly in classes where students have low pre-test scores. It is also important to provide support for instructors new to IE strategies.

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List of Abbreviations

BEMA .....Brief Electricity and Magnetism Assessment

CAD .....Contrasting Alternatives Design
CLASS……...Colorado Learning Attitudes About Science Survey
CSEM.....Conceptual Survey of Electricity and Magnetism

DoP .....Dimensions of Practice

EBAPS .....Epistemological Beliefs Assessment for Physical Science

FCI .....Force Concept Inventory
FMCE…….....Force Motion Concept Inventory

IE.....Interactive Engagement
ILD.....Interactive Lecture Demonstrations

MBT .....Mechanics Baseline Test
MD .....Mechanics Diagnostic Test
MPEX .....Maryland Physics Expectations Survey

NRC .....National Research Council

PER .....Physics Education Research
PI.....Peer Instruction

STEM…….....Science, Technology, Engineering, and Math

List of Symbols

g.....Normalized Gain
<g>.....Average Normalized Gain

Chapter One

Problem Statement

As enrollments at United States institutions of higher learning reach record highs, the demand for introductory classes in all disciplines, including STEM classes, has correspondingly increased (Fry, 2009; Clark, 2009; Glenn, 2010). At the same time, funding to these institutions has decreased, leading many college and universities to cut budgets, resulting in less available money for instructors, new building, or new technology in science classrooms (Clark, 2009). As a consequence, just at a time when there is more need for introductory science classes, there are fewer resources to provide these classes, leading to more large-enrollment, lecture style introductory science courses, including introductory physics, with enrollments of up to 100 or more students.

In addition, while the proportion of incoming freshmen who indicate an interest in pursuing majors in STEM fields has increased in recent years, far fewer students who start out majoring in a STEM field graduate with a STEM degree than students beginning in other majors (Epstein, 2010). According to the National Center for Education Statistics, only 15.1% of bachelor's degrees awarded in 2009 went to students majoring in the natural sciences and engineering. The total number of science and engineering degrees awarded in the United states has increased in recent decades, but at approximately one-third of the rate at which the number of available jobs in these fields had grown (Augustine, 2007). Study of these subjects, however, leads to socially and monetarily lucrative careers in science, technology, engineering, and mathematics (STEM) fields. (Hazari, et. al., 2007).

In many college and universities, the introductory physics course acts to serve a gatekeeper function for careers in physics and engineering, and also in other sciences and scientific fields like biology, pharmacy, chemistry, etc., in that students must perform adequately in the physics course in order to continue in their chosen major (Hazari, et. al., 2007; Seymour & Hewitt, 1997). Students who do not "make the grade," so to speak, and who may find the introductory physics course too challenging, often cannot continue in their chosen field (Seymour & Hewitt, 1997). The introductory physics class is often these students' first experience with university/college physics and one of their first experiences with science in general at the post-secondary level, and poor performance could discourage them from further study in physics or other scientific and technical fields (Ivie & Nies Ray, 2005; Seymour & Hewitt, 1997).

While the realities of higher education include an increased reliance on large lecture classes for physics teaching, students learn all science, including physics, best by doing scientific inquiry, in an environment that is centered on students as learners (NRC, 2000). According to the National Research Council (2000), good instruction "begins with what learners bring to the setting" (p. xvi). This type of learner centered instruction includes making knowledge accessible to students, allowing them to construct their own understanding in a cooperative setting, providing opportunities for doing guided scientific inquiry, and providing feedback and assessment that is both relevant to students' concerns and learning processes and timely and personal (NRC, 2000; NRC, 2005). In addition, Lin and Lehman (1999) showed that college students can benefit from a meta-cognitive approach, where they are asked to stop and reflect on what they are doing and why during inquiry and other activities.

Students majoring in science and engineering fields will typically take one of two types of introductory physics courses, defined mainly by the highest level of mathematics employed in each. The algebra based physics course, or college physics, is generally required for students majoring in non-physics scientific fields, such as chemistry, biology, and the biological and health sciences (pre-medicine, dentistry, radiology, etc.). The calculus-based course, or university physics, is required for students majoring in physics and engineering, although non-physics and engineering science students may take it if they wish. Both courses have roughly the same level of conceptual difficulty, although the calculus-based course is generally considered to be the more mathematically rigorous (Seymour & Hewitt, 1997). Both courses tend to cover a similar subset of physics topics and both usually consist of two semesters, with the first semester focusing on Newtonian mechanics and thermodynamics concepts and the second semester focusing on topics in electricity and magnetism, optics, and modern physics (Meltzer & Manivannan, 2002; Sadler & Tai, 2001; Hazari, et. al., 2007).

Traditionally, both college physics and university physics classes are structured to consist of a large enrollment lecture with smaller recitation, or discussion, and laboratory sections. According to the literature, some interventions beyond traditional lecture that have been implemented in large enrollment introductory physics classes include using tutorials and cooperative problem solving during the smaller recitation sections and using Peer Instruction methods and interactive lecture demonstrations with an instant response system during the large group lecture (McDermott & Shaffer, 2001; Scherr & Elby, 2007; Mazur, 1997). Taken together, these methods fall under the umbrella of interactive engagement (IE). IE methods allow students to interact with physics concepts in a way

that lets them to construct their own understanding and require students to be actively involved in their own learning.

Physics education research suggests that the use of these methods in a traditionally formatted introductory physics class consisting of a large lecture with smaller recitation and laboratory sections, improves student understanding of physics concepts and may improve student views towards physics as a subject (Pollock & Finkelstein, 2008; Deslauriers, et. al., 2011). Aspects of interactive engagement that may contribute to this success include requiring students to work cooperatively with each other, think deeply about physics concepts, and revise their ideas about physics. In addition, the timing of the interventions, making students' reasoning visible to instructors and students through the use of instant feedback devices, and the increased instructor guidance it is possible to provide in a smaller recitation section using tutorials may also play a role in increasing student conceptual understanding of and more physicist like views about physics.

Some institutions offer introductory physics courses that do not include a separate recitation session; instead, the class includes only the large lecture and laboratory sections. When the introductory physics course is structures in this way, students do not have the opportunity to break into smaller groups for discussion. No research has been located that looked into the effectiveness of using IE methods meant for smaller groups, like tutorials, in conjunction with Peer Instruction activities and interactive lecture demonstrations meant for use in larger groups to improve student learning of physics concepts and views toward physics as a subject in introductory physics classes that do not include separate recitation sessions.

Purpose Statement

The purpose of this study is to investigate whether the use of interactive engagement methods, including tutorials, Peer Instruction, and interactive lecture demonstrations, can overcome the limitations of a large enrollment college physics class without a separate recitation section and improve student conceptual understanding of and views toward physics. Typically, some of these limitations, such as the lack of one-on-one interaction between students and instructors and the lack of individual feedback to students, are addressed by the use of a smaller enrollment recitation section. Since these methods, particularly the use of tutorials, have mainly been studied in classes with smaller enrollment recitation sections, this study also explored which aspects of interactive engagement techniques (increased student cooperation, thinking deeply about physics, revision of ideas, timing of interventions, making student reasoning visible to instructors and students themselves, and increased instructor guidance) are associated with improved student learning of and views toward physics in a large enrollment introductory physics class without a separate recitation section. This study also explored which features of these tasks are the most important for use in a large enrollment class without a separate recitation section and what modifications should be made by the instructor to the methods, as reported in the literature, that facilitate the use of these methods in such a class.

Research Questions

- What do students learn about physics concepts and how does student learning in this course compare to that reported in the literature for students in a traditional college physics course?

- Do students' views about physics change and how do students' views compare to that reported in the literature for students in a traditional college physics course?
- Which of the instructional strategies contribute to improved student conceptual understanding and more physicist-like views of physics in this course?

This study took place during the first semester of a two-semester introductory college physics class. The class typically enrolls approximately 150 students in their sophomore or junior year of college and does not have a separate recitation section. The class was taught using modified interactive engagement methods, including the use of Peer Instruction, tutorials, and interactive lecture demonstrations. The extent to which these methods improve student understanding of physics and views toward physics was investigated by measuring the gains between pre- and post-instruction on a test of conceptual understanding of physics and a survey of students' views about physics. The important features of the modified interactive engagement methods that contribute to student learning and views were investigated through the use of student interviews and transcribed recordings of student conversations during tutorials and Peer Instruction.

In this dissertation, I will review the literature around what it means for students to learn physics and the methods most commonly used to measure student learning. Then I will describe the methods used in this study and the findings. I will discuss the findings of this research and put those findings into the context of previous research on this topic. Finally, I will discuss implications of this research and some recommendations for future research on these topics.

Chapter Two

Literature Review

The goal of any introductory physics course is for students to learn physics. However, this can mean different things for different people. For students, learning physics often means that they have memorized a list of facts and that they know which equation to use to solve various types of standard, end of chapter problems. Students also typically feel that a good grade in the course is indicative of the extent of physics learning that has occurred. Instructors, on the other hand, tend to want students to understand physics concepts and to be able to apply those concepts to explain a wide variety of phenomena.

Traditionally, instructors have taught introductory physics classes by lecturing to students and then assuming that students have learned physics, with the only assessment being exams and homework typically consisting of "plug and chug" problems and lower order qualitative questions (Leonard, 2000; Cooper & Robinson, 2000; Handelsman, 2004). Unfortunately, the result of traditional instruction in introductory physics courses most often aligns with students' conception of learning physics instead of that of instructors. Instructors may think that students truly understand physics concepts and will be able to transfer that knowledge to various situations, but in reality, the results of education research point to just the opposite conclusion; students leave introductory physics classes no better off than when they started, and sometimes even worse (Wieman & Perkins, 2005; Handelsman, et. al., 2004; Cooper & Robinson, 2000; Halloun & Hestenes, 1985; Elby, 2001).

In recent decades, as education researchers and cognitive psychologists have published research about how people learn, physicists and physics education researchers have become more interested in using research based pedagogy to improve student learning in introductory physics. This necessitates the development of teaching methods that lead to improved student learning of physics and the development of instruments and other methods of measuring student learning. The main goal of this literature review is to define a consensus view of what it means to learn physics, summarize research into how people learn science in general and physics in particular, and to discuss some reformed teaching methods that have been shown to produce improved student learning of physics in large enrollment, introductory physics classes.

What Does it Mean to Learn Physics?

According to the literature on the topic, learning in physics has many different aspects. As early as 1903, Robert Millikan stated, "it is grasp of principles, not skill in manipulation, which should be the primary object of General Physics courses" (p. 3). More recently, physics education researchers and others point to two highly intertwined aspects of physics learning: conceptual understanding of physics topics and views about physics as a subject. The goal of physics instruction is often to guide students to more expert-like understanding of and beliefs about physics (Weiman & Perkins, 2005; Redish & Hammer, 2009; NRC, 1999).

Conceptual understanding of physics refers to student learning of the facts and figures of physics content, including the various principles, theories, and terminology of physics, as well as students' abilities to use that knowledge to predict and explain various phenomena (Duda & Garrett, 2008; Redish & Hammer, 2009; Weiman & Perkins, 2005).

According to Reif (1995), in order for students to effectively use their conceptual knowledge of physics, it must be organized in such a way that allows efficient access to needed information. Unfortunately, students' knowledge of physics, often even after instruction, is typically disorganized and incoherent; students tend to view physics concepts as a set of unconnected facts (Halloun & Hestenes, 1985; Reif, 1995; Redish, 1994; Wieman & Perkins, 2005). In addition, it is not enough for students to demonstrate an ability to use physics knowledge to solve problems and explain phenomena during instruction. If students have truly gained a conceptual understanding of physics, they should also be able to add new knowledge to their existing organizational structures and retain and use that knowledge after instruction is over. By contrast, physicists' knowledge tends to be arranged in a very hierarchical structure, with many ideas and concepts subordinate to a few main ideas (Reif, 1995; Redish, 1994). There is some evidence that knowledge organized in this manner is more easily accessed and used by students to perform various tasks as well as being retained for longer periods of time (Eylon & Reif, 1984).

The other main aspect of physics learning is students' views about physics. What I will call students' views of physics is referred to in the physics education literature as students' attitudes and beliefs about physics. Attitudes are general positive or negative feelings about a subject, while beliefs are often described as the basis for attitudes; they provide information that may be used in forming attitudes about an issue or subject (Koballa & Glynn, 2007). Views about physics can have multiple dimensions, including liking physics, enthusiasm about physics, beliefs about the difficulty of physics and who can do physics, self-efficacy beliefs, and epistemological beliefs. Views about physics

are correlated with student learning of physics, particularly in the dimension of self-efficacy about one's ability to do physics and epistemological beliefs about physics (Koballa & Glynn, 2007; Kortemeyer, 2007). This is because self-efficacy is related to the effort one is willing to expend on a task, even though it is not necessarily correlated to students' actual abilities, rather than their beliefs about their talents and abilities (Pajares, 2002). Epistemological beliefs refer to beliefs about the nature of physics and physics learning. Physicists and other experts tend to view physics as a way of thinking that is coherent and organized according to underlying physics concepts, whereas students tend to view physics as a collection of facts and formulas that is organized according to surface features (Kortemeyer, 2007).

Taken together, conceptual understanding of physics and views about physics are the main aspects of physics learning. However, these two strands alone are not enough. Students should also be able to retain this knowledge and use it in many different contexts and situations even after instruction has ended (NRC, 1999; Weiman & Perkins, 2005). In order to say that students have truly learned physics, they should have developed expert-like competencies in acquiring and structuring conceptual knowledge of physics so that it is useful in various contexts (Wieman & Perkins, 2005). Students should also have developed expert-like views about physics that allow them to view the subject as an interconnected whole based on a few very important principles, which will aid them in developing the organizational structure needed to apply their knowledge to problems in everyday life both in and out of the classroom.

What Do We Know About Learning?

Learning science. By the time students enter high school or college, some have the ability to reason formally about abstractions, but most will still need to see, touch, or hear something to understand it (Leonard, 2000). This means that many students will not learn science by listening to professors tell them information or by reading textbooks. Instead, these students will need to interact with scientific concepts in a way that they can use to construct their own understanding, in an environment that is centered on them as learners (NRC, 2000). In *How People Learn: Science in the Classroom* (2005), the National research council identifies three main principles of teaching and learning: identifying and addressing preconceptions, knowledge of what it means to "do science," and metacognition. All of these require that learners actively interact with the concepts and build their own understandings of science concepts.

The first principle refers to the fact that students enter the science classroom with previous notions of how the world works, based on their prior experience. These notions, while generally false, are not unreasonable, but they are often very limited and contrary to scientific reasoning. Many of these prior notions can prove to be very resistant to change. As they learn new concepts and ways of looking at the world, students typically will try to connect new concepts to their existing understanding. If successful, this can lead to a deeper understanding of scientific concepts, but if not, students will often revert to their prior understandings or misconceptions (Leonard, 2000; NRC, 2000; NRC, 2005). In order to increase the likelihood of success, instructors should engage student preconceptions directly and help them to replace those incorrect or limited prior notions with scientifically sound ideas.

The second principle refers to the fact that not only do students begin science classes with naïve notions of how the world works, they have equally naïve ideas of what it means to "do science" at all. Students often think that "doing science" means following a set of concrete steps to get the "right" answer, with very little imagination or reasoning involved (NRC, 2005). As with understanding scientific concepts, students need to actively engage in the process of performing experiments or making observations and also making inferences and reasoning through to conclusions in order to really understand, conceptually, what it means to "do science" and how the process of science works.

Finally, the third principle of learning science put forth by the National Research Council is metacognition. Students are rarely asked to consider why they give answers to particular questions and to think through their own reasoning about a concept or problem. Lin and Lehman (1999) demonstrated that students could benefit from a metacognitive approach to teaching science, with instructors asking students explicitly to reflect on their own thinking about concepts and their own role in scientific investigations. They showed that students who were asked to do this performed significantly better on tests of conceptual understanding that students who did not perform the metacognitive tasks. This is also related to student's epistemological beliefs about science. Students that develop the habit of reflecting on their thinking about learning scientific principles also understand the importance of consistency and coherence in scientific reasoning and will be better prepared for advanced work in scientific fields (Elby, 2001).

Learning Physics. The principles of learning and teaching science put forth by the National Research Council will also necessarily apply to physics, and much of the

work on student learning and cognition in science has, in fact, been done in the domain of physics (NRC, 2000; NRC, 2005). However, many physics education researchers would argue that the problem of how students learn science is more pronounced in physics. Duit, Niedderer, and Schecker (2007) state that "…physics learning includes difficulties that are due to the particular nature of physics" (p. 599). They and others argue that because physics knowledge is needed for understanding phenomena that students will encounter in their daily lives as citizens in ways that other domains in science are not, it becomes important to study how people learn physics specifically, in addition to the more general studies of how students learn science. They also note that students view physics as particularly abstract, complicated, and counterintuitive as compared to other sciences (Duit, et. al., 2007; Elby, 2001; Wieman & Perkins, 2005; Reif, 1999; Redish, 1994; Redish & Hammer, 2009; Gire, et. al., 2009; Halloun & Hestenes, 1985).

Redish (1994) has pointed to the importance of allowing students to build their own "mental models" of physics concepts, while also keeping in mind that it is easier for students to learn material that extends or modifies a pre-existing mental model than to create an entirely new one. This reinforces the idea that instructors should be mindful of students' prior notions of physics concepts and help students modify those existing models where necessary. However, this can prove to be especially difficult for students in physics, due to the higher levels of abstraction required to understand basic physics concepts like force, energy, or electric current (Duit, et. al., 2007). More recently, many physics education researchers are focusing on the importance of metacognition and epistemological beliefs to physics learning. Research has shown that students can learn physics concepts without fundamentally challenging their epistemological beliefs about

physics (Elby, 2001; Adams et. al., 2006; Kortemeyer, 2007). The danger in this is that although students may perform better in a particular class or during instruction, they are likely to revert to their original learning strategies and mental models of physics in subsequent courses or environments (Elby, 2001).

What Instructional Methods Lead to Improved Student Learning of Physics?

Traditional Instruction. Despite research showing that students learn best when they are allowed to construct their own understanding in an environment that promotes active engagement with each other and with the concepts being learned, introductory physics courses are typically large enrollment courses traditionally taught by lecture (Glenn, 2010; DeHaan, 2005). In the lecture hall, the instructor stands at the front of the room and presents course material and problem solving techniques while the students passively take it all in and write notes. Lindenfeld (2002) calls this approach "animated textbook" (p. 12). The classroom is often very large, so that students in the back cannot see or hear what is being presented. These classes typically suffer from low attendance, lack of student engagement during class time, and few opportunities for students to construct their own understanding of course material (Riffell & Sibley, 2005; Walker, et. al., 2008). Students in these courses often complain of being bored of "classes that are filled with isolated facts that (they) are expected to memorize …, and tests that assess little more than students' ability to remember such facts" (DeHaan, 2005, p. 254). In addition, it is difficult to assess students' learning or provide meaningful feedback individually during instruction. The traditional lecture environment is not very well structured for student understanding and students are in an environment that, at best,

promotes passive learning and rote memorization (Meltzer & Manivannan, 2002; Cooper & Robinson, 2000).

Despite these difficulties, the large lecture class does have some advantages. This type of instruction lends itself well to providing quick and efficient review of material, providing examples of problem solving techniques, and providing context or background for information found in reading material (Cooper & Robinson, 2000). Also, in a large lecture class, there will be a diversity of students of different backgrounds, cultures, and learning styles, providing an advantage to students in terms of study groups and class discussions (Wolfman, 2002). A good lecture can also take advantage of a group mentality of large crowds, or what Wolfman calls an "infectious enthusiasm" that can help to keep students engaged in learning science (p. 258).

Interactive Engagement Methods. Current research in improving the traditional introductory physics class focuses on making that environment more interactive for students and instructors and giving students more opportunity for constructing their own knowledge. According to Mestre (2001), this has two implications for teaching: prior knowledge affects students' ability to learn new material and instructors should favor methods that allow students to construct their own knowledge over those that do not. Alternative methods of teaching large introductory physics courses have been developed in recent decades that have been shown to increase student understanding of physics concepts. These methods are variations on the theme of making the physics lecture more interactive so that students are actively involved in the learning process rather than passively receiving information.

Many researchers advocate making explicit the "hidden curriculum" of the introductory physics course, which is implicit in instructor expectations of students. Aspects of this hidden curriculum include encouraging students to engage in scientific reasoning and make connections between various physics concepts and their everyday lives, leaving students with positive views towards physics, and allowing students to engage in metacognitive thinking about their own learning (Duda & Garrett, 2008; Redish & Hammer, 2009; Walker, et. al., 2008). Unfortunately, many aspects of the traditionally taught physics lecture course, such as passively listening to instructors, solving standard end-of-chapter problems, and memorizing large amounts of information undermine student acquisition of skills included in this hidden curriculum (Redish & Hammer, 2009). In fact, students often leave these classes with impressions that are the exact opposite of the ideas we would like them to have about physics and physics learning (Elby, 2001; Duda & Garrett, 2008).

Interactive engagement strategies in the large enrollment introductory physics lecture course allow students to become more involved in their own learning and to transform the lecture hall into a cooperative setting where students can construct their own understanding of physics concepts. Actively engaging students in their own learning in lecture-based classes can be facilitated in a variety of ways, including Peer Instruction, Interactive Lecture Demonstrations, innovative uses of group work, such as Peer Led Guided Inquiry, tutorials, and collaborative problem solving, and the use of social media in the lecture course, such as blogs, discussion boards, and Twitter.

Peer Instruction. The most widely used and tested of these methods is Peer Instruction (Mazur, 1997). In this method, the lecture is interrupted periodically and

students are asked a series of conceptually challenging multiple-choice questions, called ConcepTests, that are specifically designed to uncover common misconceptions that students have about introductory material (Mazur, 1997). The method follows a set instructional sequence. First, students are asked a question and given a few moments to think about the answer on their own, then the class "votes" on the correct answer. If a large majority of students answer correctly, the instructor confirms the correct answer, steps students through the reasoning, and moves on. If approximately between 30-70% of students answer correctly, then students are asked to break into groups of two or three to discuss their answers among themselves before the class is asked to answer again. The instructor then leads a class discussion on the reasoning involved and elicits student explanations of the correct answer. Typically, this second "vote," after student discussion, results in a much larger percentage of correct answers. However, if a large majority of students answer incorrectly, the instructor will typically change course to ask a slightly easier question, gradually building the students conceptual understanding with peer and class discussion until they are able to reason through the initially difficult question.

Use of Peer Instruction in introductory physics classes has been shown to lead to marked improvements in student understanding of physics concepts (Mazur, 1997; Meltzer & Manivannan, 2002; Lasry, et. al., 2008; Mellema, 2001; Turpen & Finkelstein, 2009). However, for this method to be successful students must be allowed to think about and discuss solutions to these questions and there must be some way for the instructor to receive instantaneous results from all the students simultaneously, such as flashcards or clickers (Meltzer & Manivannan, 2002). The use of the instantaneous

feedback devices allows instructors to access information about student understanding of concepts or student misconceptions in "real time," as the class is going on. This way instructors can modify their approach to explaining the material or modeling problem solving as needed, or spend more time on one topic or another, so that students can develop a better understanding of the material.

Lasry, et. al. (2008) compared student performance on tests of conceptual understanding of physics topics in introductory physics classes taught using Peer Instruction and those taught using traditional lectures at a two year community college in 2005 to students taught with both methods at Harvard University in 1990-1991 (the first year Peer Instruction was used at Harvard). They found that at the community college, Peer Instruction was more beneficial to students with higher levels of background knowledge, as measured on pre-instruction administration of the conceptual tests, compared to students with less background knowledge, but that both groups benefitted from Peer Instruction compared to students in the traditional class. They also found that while Peer Instruction focuses more on conceptual understanding than quantitative problem solving, students in the peer instruction section performed as well on a final exam that was made up of 90% quantitative material and problems as students in the traditionally taught section, while also scoring significantly higher on post-instruction administration of the tests of conceptual understanding. They conclude that Peer Instruction increases students' quantitative reasoning and problem solving skills at the same rate as the traditional lecture while significantly increasing students' qualitative, conceptual understanding of the material. They also found that far fewer students dropped the course in the Peer Instruction sections than in the traditional sections,

implying that the students in the Peer Instruction sections were more highly motivated to learn physics than students in the other sections. Despite vastly different student populations, these results are consistent with the results of the first year course taught with Peer Instruction at Harvard.

Meltzer and Manivannan (2002) performed a similar comparison of student performance using a variation of Peer Instruction they developed that requires even more student involvement during class time, with less time spent on instructor lecturing. They have all but given up on efforts to spend class time presenting derivations or detailed explanations of concepts. Instead, class time is used almost exclusively in a continuous interchange of questions and answers between students and the instructor. The class typically begins with a short "mini-lecture" to introduce a topic, then students are asked a series of progressively more difficult multiple choice questions. As in Peer Instruction, students first think on their own then discuss answers with each other. After each question, the instructor leads a class discussion on the topics under investigation before posing another question. This variation on Peer Instruction requires that the instructor be able to tailor succeeding questions to student difficulties and the class discussion at hand and increases student interaction dramatically compared to Peer Instruction as originally conceived. The results of this study was that students in the treatment class, using their variation of Peer Instruction, performed significantly higher on tests of conceptual understanding of physics than did students in a traditionally taught course as well as scoring higher on similar final exams. They also note that there is some evidence that courses where a more conceptual understanding is emphasized might do more to prepare students for pre-professional exams such as the MCAT. These results have been

replicated at in other universities with varying levels of success with differing student populations and differing implementations of Peer Instruction (Turpen & Finkelstein, 2009; Willoughby & Gustafson, 2009).

Interactive Lecture Demonstrations. Another variation of interactive engagement and cooperative learning in the large, introductory physics lecture is the Interactive Lecture Demonstration (Crouch, et. al., 2004; Milner-Bolotin, et. al., 2007). Here, the instructor sets up a demonstration and allows students to predict the outcome of the experiment. Students write down their predictions and the instructor solicits predictions from the class. The instructor then chooses the most common predictions and projects them for students to see. Students are then asked to discuss their predictions with each other and, after a few moments, "vote" on their predictions with an instant feedback system, using the most common choices solicited by the instructor as possible answers. The instructor then performs the demonstration and students discuss the outcomes among themselves, in small groups, comparing predictions with observation and discussing any possible reasons for discrepancies, before the instructor leads a whole class discussion about the outcome. Research into this method shows that students in classes where Interactive Lecture Demonstrations were used performed better on assessments of concepts related to the demonstrations than in classes where students merely observed the demonstration with no prediction or discussion (Crouch, et. al., 2004; Redish & Hammer, 2009).

Group Work. Another strategy for increasing student engagement in the introductory physics course is to allow students to work together on assignments and activities that require them to think deeply about concepts and work through problems

during class time. One variation on this type of "group work" intervention is Peer Led Guided Inquiry (Lewis & Lewis, 2008). In Peer Led Guided Inquiry, the lecture is broken up into short "mini-lectures" and short, guided inquiry activities. Students are divided into several groups of three or four and spend a large portion of class time working together on these inquiry activities and discussing the results with each other. The activities are carefully placed so that students can investigate a topic before it is discussed in the lecture. Students also perform relevant homework before the Peer Led Guided Inquiry session to get them thinking about a concept and they are quizzed frequently throughout the term. Lewis and Lewis (2008) found that the use of Peer Led Guided Inquiry techniques in addition to traditional mini-lectures was associated with higher performance on final exams for all students.

There have been few studies found in the literature that investigate the use of variants of Peer Led Guided Inquiry in an introductory physics class. Meltzer and Manivannan (2002) developed the *Workbook for Introductory Physics* containing similar activities that emphasize qualitative reasoning and that target student learning difficulties that have been reported in the literature. In addition, tutorials for use in smaller recitation sections of introductory physics classes have been developed that could be used or modified for use in a introductory physics lecture (McDermott & Schaffer, 2002; Scherr & Elby, 2007). In particular, the Open Source Tutorials have been used for this purpose, although no studies have been done investigating their effectiveness when used in this manner (Scherr & Elby, 2007). In addition, Mellema (2001) reports the use of a similar technique for collaborative problem solving, where students are broken into groups and asked to solve difficult, "context-rich" problems that require students to make

assumptions and reason through their solutions. This approach has been found to increase student reasoning and problem solving abilities in introductory physics classes (Mellema, 2001).

Social Media. One type of social media that can be used to increase student interaction with each other and instructors outside of the classroom is the course blog. According to Ferdig and Trammel (2004), blogs are useful teaching and learning tools because "they provide a space for students to reflect and publish their thoughts and understandings. And because blogs can be commented on, they provide opportunities for feedback and potential scaffolding of new ideas" (p. 1). Blogs also allow students who feel uncomfortable speaking up in class to contribute to class discussions and allow in-class discussions to continue long past the time when the class meeting ends. In addition to this, student authored blog posts allow students to apply the concepts learned in physics class to other aspects of their lives. In other words, the process of writing blog posts about physics and tying content to concrete, everyday experiences helps students see what physics is "good for" (Duda & Garrett, 2008). In addition to this, Duda and Garret (2008) have suggested that students who use blogs in physics class spend more time outside class finding and synthesizing information to include in posts and comments than they generally would with standard homework alone.

According to the literature, blogging in the introductory physics class can provide several benefits to students. These include increased student interest and ownership of their own learning, increased student participation in class discussions, and, since blogs can be made open to a wider audience than just the physics class, opportunities for exposure to diverse perspectives. The use of blogs in introductory physics classes also

allows students to become more expert on the subject matter of science. Writing and replying to blog posts also requires students to sift through large amounts of information and forces them to think critically about what constitutes good science and how it relates to their lives (Brownstein & Klein, 2006; Duda & Garrett, 2008; Ferdig & Trammell, 2004).

Another type of social media that could be used in the introductory physics class is Twitter. Twitter is a microblogging service that allows users to send short messages, up to 140 characters, to each other quickly and in real time. Twitter can be used during an introductory physics class to help facilitate class discussion among many students. Ferenstein (2010) and Young (2009) suggest that using Twitter during class time in this manner can increase student participation in class discussions and help keep students engaged with concepts during the lecture. Because the technology is so new, no research on the use of Twitter in an introductory physics course was found. However, Junco, et. al. (2011) investigated the use of Twitter in a first year seminar course for pre-health professional majors. They used Twitter in several ways in the course, mainly outside the classroom: to continue class discussions, to allow students to ask questions, to discuss readings in the textbook, class and campus event reminders, and organizing study groups. They found that student engagement increased over the course of the semester for students in the class that used Twitter as compared to students in the class that used a more common class website, such as Blackboard, exclusively. They also found that students in the class using Twitter received higher grades as compared to students in the class that did not. It would be interesting to see a study that investigated the use of

Twitter or other microblogging services in introductory physics courses and this seems to be a promising area for future research.

Issues with Interactive Engagement Methods. The use of inquiry based, interactive engagement strategies in a large enrollment introductory physics classroom have been shown to increase student performance and understanding of science concepts. However, as with any set of strategies, there are some drawbacks to these approaches. These include limitations of topics that can realistically be covered over the course of a semester, student attitudes toward unfamiliar teaching methods, and increased demands on instructors.

Limitations on Topics Covered. When using the strategies discussed above to increase student engagement and collaboration in introductory physics classes, significant class time needs to be spent letting students discuss ideas and ask questions. In a lecture, this time would be spent covering new topics or solving sample problems, but in an interactive engagement class, instructors must choose only a few of the array of topics generally taught in the introductory physics class for in depth treatment. There simply is not enough instructional time during the course of a semester to treat every topic and subtopic in the depth required for these strategies that the traditional lecture course can deal with. However, there is evidence that, although students do not get exposed to the breadth of topics that can be covered in a traditional lecture class, they will have a much deeper understanding of the topics they have seen and will be more likely to have developed the skills to transfer that knowledge to various situations and contexts (Meltzer & Manivannan, 2002; Tai, et. al., 2006).

Consistency of Implementation. Turpen and Finkelstein (2009) performed a study of various instructors' implementations of Peer Instruction in introductory physics classes and found that the degree to which instructors communicated expectations to students and the degree of student-professor interactions during the academic task greatly affected student gains on tests of conceptual understanding of physics. They discuss several practices students engage in that are associated with the use of Peer Instruction in introductory physics classes including discussing physics content with their peers, debating physical reasoning, formulating and asking questions, and interacting with physicists. They found that different instructors implementations of Peer Instruction allowed students to experience these in varying amounts and that students who had opportunities to practice all of these regularly performed better on tests of conceptual understanding than students whose instructors provided these experiences unevenly or inconsistently, although students in all the Peer Instruction classes performed better than students in traditional lecture classes.

Demands on the Instructor. There is no question that teaching a large lecture course using interactive engagement strategies is much more difficult and time consuming for the instructor than teaching a standard lecture course. In addition to preparing notes or other materials for class as the traditional lecturer might do, the instructor using these strategies must carefully choose and prepare guided inquiry activities such as tutorials or problems for group work and discussion as well as preparing questions for Peer Instruction. This instructor may spend several extra hours a week preparing materials, creating thoughtful class blog posts, and providing well though out feedback for students on their on contributions to classroom blogs (Lasry, et. al., 2008;

Duda & Garrett, 2008; Meltzer & Manivannan, 2002; Redish & Hammer, 2009). The instructor will also need to be more flexible during class time, prepared to explore concepts in great depth at very short notice or to refocus and redirect class discussion if necessary.

Student Attitudes. Just as the instructor using these improvement strategies in the introductory physics course faces extra demands on time and mental facilities, the students in these classes face similar issues. In the traditional lecture, students know what to expect of the instructor and themselves and many feel that they know how to cope with those demands. In a class where these strategies are implemented, however, students can become unsure and nervous, and even angry (Redish & Hammer, 2009). In these courses, students can no longer sit back and observe the lecture; they must instead be active participants in the learning process. They must be prepared to spend more time and effort, both inside and outside of class, learning new material and understanding concepts and they should be prepared to discuss their ideas with each other and possibly defend their understanding of a new concept (Meltzer & Manivannan, 2002; Redish & Hammer, 2009). After students become used to the classroom atmosphere and the increased demands, though, many find that they understand physics concepts better than their peers in more traditional lecture courses and they come to enjoy the class. This type of instruction also increases student attendance in introductory physics classes and reduces the percentage of students who withdraw from the course (Cooper & Robinson, 2000; Meltzer & Manivannan, 2002; Redish & Hammer, 2009).

Discussion of Instructional Methods

While the reforms discussed in the literature review have all been shown to improve student conceptual understanding of physics, there is evidence that even these reforms do not necessarily improve student views about physics (Elby, 2001; Adams et. al., 2006; Kortemeyer, 2007). According to Redish and Hammer (2009), the structure of other aspects of the introductory physics course undermines students' learning gains received from the in-lecture interventions discussed previously and may partly explain students' lack of improvement in views of physics. Redish and Hammer argue than the typical "cookbook" laboratory activities and passive review sessions in recitation that typically accompany the introductory physics lecture promote the rote learning that students expect from previous experiences in science classes. Combined with a reformed lecture component of the course, this can send mixed messages to students about what is important in physics classes and cause confusion. Instead, they argue for a complete redesign of every aspect of the introductory physics course where in addition to the use of Peer Instruction and Interactive Lecture Demonstrations in the lecture component of the course, the laboratory component, the recitation, homework, and assessments are all reformed so that the hidden curriculum in introductory physics classes is made explicit and attention to student epistemological development runs through every aspect of the course.

Redish and Hammer (2009) adopted this approach in introductory physics classes for biology and pre-health professional students at the University of Maryland. They implemented Peer Instruction and Interactive Lecture Demonstrations during lecture and also reformed the laboratory, recitation, and homework for the course. In the laboratory,

instead of having students perform pre-scripted activities to arrive at a desired result, the group designed the Scientific Community Labs. These activities consist of a question that can be answered empirically. Students are then required to work in groups to design an experiment using available laboratory equipment to answer the question, write group reports that are evaluated on thoughtfulness and thoroughness, and present their findings to the class. Topics covered in the laboratory are not necessarily correlated in time to when topics are covered in lecture. Instead, the focus of the laboratory is to get students to think about how to do physics as an empirical science and to prime them for later theoretical development.

Traditionally, recitation sessions are homework review sessions run by teaching assistants. Teaching assistants go over solutions to homework problems, hand back previous work, and answer any questions that students may have about assignments. Instead of the traditional recitation, Redish and Hammer (2009) implemented tutorial sessions. They modified existing tutorials—the *Tutorials in Introductory Physics* (McDermott & Shaffer, 2002) and *Activity Based Tutorials* (Wittmann, Steinberg, & Redish, 2004)—to stress student epistemological development. These tutorial sessions are still run by teaching assistants, but instead of watching homework solutions be presented, students worked in small groups doing activities designed to help them develop conceptual understanding engage in metacognitive reflection about their learning.

Finally, homework and assessments for the course were also re-designed to be more in line with the epistemological and conceptual focus of the course. Instead of assigning standard, end of chapter problems, the group instead developed homework

assignments designed to challenge students conceptually and require them to reason through ideas logically. Students were encouraged to work in groups on homework assignments outside of class and instructors and teaching assistants were available during extended "help session" hours for students to get extra help. In order to continue with the emphasis on conceptual understanding and epistemological development of students, quizzes and exams were also re-designed to bring them more in line with these goals. Exam and quiz questions were focused on having students explain their reasoning in addition to providing an answer, so that students are again encouraged to think metacognitively about their learning even during assessments.

Redish and Hammer (2009) compared students' scores on tests of conceptual understanding and epistemological surveys for students in the completely reformed classes with results of best practices reported in the literature. They found that students in their reformed class showed gains on tests of conceptual understanding comparable to the best results reported in the literature, while also showing significant improvement on epistemological surveys instead of the losses typically reported in the literature. However, they caution that many of the same issues associated with interactive engagement methods will also apply here, including severe restrictions on topical coverage and consistency of implementation of both the interactive engagement strategies throughout the course as well as keeping mindful of student epistemological development.

Conclusion

The research discussed above shows how an introductory physics course can be modified to increase student conceptual understanding of physics. In class strategies,

such as the variations on group work, implementing Peer Instruction using clicker or other instant feedback technology, and Interactive Lecture Demonstrations have all been shown to improve student conceptual understanding of physics. In addition, there is some evidence that out of class interventions, such as student blogs and other uses of social media, require students to reflect metacognitively on connections between physics concepts and their everyday lives and increases the time spent thinking about and doing science. This, in turn, increases student learning of physics concepts and the nature of physics and scientific inquiry. Implementing just one of these strategies can increase student gains on tests of conceptual understanding by a measureable amount and Meltzer and Manivannan (2002) show that implementation of several reforms in the same course can lead to vastly improved student conceptual understanding.

However, none of these strategies directly addresses student attitudes toward physics and epistemological beliefs about what it means to learn and do physics and so the result is that students leave even reformed physics classes with no improvement and sometimes even a decline in their views about physics and what it means to do physics. More recently, research in physics education has begun to focus on student views and preliminary results show that when students' epistemological beliefs are attended to as part of a reformed curriculum, students' views about physics improve along with conceptual learning. This approach does have some disadvantages. Fewer topics can be covered during the course and the demands on the instructor, in terms of class preparation and thoughtful grading and feedback, are much higher than in even most reformed courses. Instructors considering this approach will need to decide if the trade-off is worth it. Overall, though, implementing even a few of the reforms discusses here has been

shown to increase student understanding of difficult physics concepts, increase student retention of knowledge, and increase student acquisition of thinking skills that can apply to all aspects of their lives.

Chapter Three

Methods Review

Quantitative Instruments for Measuring Student Learning

In order to evaluate whether instructional goals have been met, over the last thirty years physics education researchers have developed several instruments to measure student understanding of some of the more basic concepts of physics as well as student views towards and beliefs about physics and physics learning. The main approaches that have been taken with the development of the conceptual surveys has been to develop a survey that focuses on student learning of a few very key ideas in physics or to develop a survey to measure student learning of a broader range of concepts. The most common conceptual surveys used in physics education research include the Force Concept Inventory, the Mechanics Baseline Test, the Force and Motion Conceptual Survey, the Conceptual Survey of Electricity and Magnetism, and the Brief Electricity and Magnetism Assessment (Halloun & Hestenes, 1985; Hestenes, et. al., 1992; Hestenes & Wells, 1992; Thornton & Sokoloff, 1998; Maloney, et. al., 2001; Ding, et. al., 2006). Surveys have been developed that focus on student epistemologies and attitudes toward physics learning in general as well as in particular courses. The most common surveys used are the Views About Science Survey, the Maryland Physics Expectations Survey, the Epistemological Beliefs Assessment for Physical Science, and the Colorado Learning Attitudes About Science Survey (Halloun & Hestenes, 1998; Redish, et. al., 1998; White, et. al., 1999; Adams, et. al., 2006).

Conceptual Learning. The Mechanics Diagnostic Test (MDT) was the first instrument developed to measure student conceptual understanding of physics (Halloun

& Hestenes, 1985). This survey was designed specifically to probe the extent to which student common sense beliefs about force and motion are affected by instruction in introductory physics courses. This test is limited to ideas in Newtonian mechanics only, mainly because first semester introductory physics classes deal with Newtonian mechanics and also because mechanics is "an essential pre-requisite for most of the rest of physics." (Halloun & Hestenes, p. 1043). This instrument consists of both physics and mathematics diagnostic tests, so that students' understanding of physics concepts and their math skills can be assessed. The authors also wish to probe the extent to which students' pre-instructional mathematical reasoning skills are correlated with gains in conceptual understanding. Questions on the MDT were initially selected to assess students' qualitative ideas about motion and forces and early versions of the test were given to students in large enrollment introductory physics courses as open ended questions. The most common student misconceptions were then used as distracters in the later multiple-choice version of the test.

Statistical analysis of the test showed that student pre-test scores were consistent across many different student populations, that the physics and math portions of the test assess different components of student knowledge, and that the two component tests together can predict student performance in introductory physics than all other variables considered in the study. The authors suggest that the MDT could be used in several different ways. They suggest that it can be used as a placement exam, to identify students who may need remedial instruction, as a diagnostic test for identifying student misconceptions, or as an instrument to evaluate the effectiveness of instruction.

The Force Concept Inventory (FCI) was developed in order to improve on the Mechanics Diagnostic Test and is based on it (Hestenes, et. al., 1992). The FCI is designed to give a more systematic and complete profile of common misconceptions in mechanics. Slightly more than half of the questions on the FCI were taken directly from the MDT, although the mathematics questions were removed entirely, and the new questions were designed and validated in a similar way. The FCI forces students to choose between a Newtonian explanation and "commonsense" explanations for various phenomena and the authors contend that student scores on the FCI give instructors and researchers insight into student thinking both before and after instruction. The FCI tests students on the following Newtonian concepts: kinematics, Newton's laws, the superposition principle, and various kinds of forces, including contact forces, air resistance, and gravity. The test probes common student misconceptions about these topics, which the authors have grouped into six "commonsense categories" that correspond closely with the Newtonian concepts in the FCI. These "commonsense categories" of student misconceptions are kinematics, impetus, active force, action/reaction pairs, concatenation of influences, and other influences on motion, including resistance and gravity, with clusters of questions providing information about misconceptions in each of these categories.

The authors of the FCI contend that poor scores on the test are just as informative as good student scores. Particularly, they say that examining student wrong answers on pre-tests can give instructors valuable information about student ideas and misconceptions and allow instructors to tailor their teaching specifically to their students' needs. However, they caution against placing too much weight in the answer to any one

question on the test, as results of interviews show that students can sometimes provide Newtonian answers to questions for incorrect reasons. Therefore, they suggest that the overall scores in each of the "commonsense categories" may provide a more general and useful indication of student misconceptions than the answers to any particular question. Like the MDT, the FCI is intended for use in both instructional and research settings. The authors particularly recommend using the FCI as a diagnostic test and say that basing student interviews on the test, by having a few students explain their answers to various questions on the FCI, can give instructors and researchers valuable information about student thinking. They also suggest that the FCI can be reliably used as a tool for evaluating the results of instruction and the effectiveness of various types of interactive engagement methods as compared to traditional teaching methods.

The Mechanics Baseline Test (MBT) was developed alongside the FCI and is meant to be a companion to it, assessing more formal knowledge about mechanics than the FCI (Hestenes & Wells, 1992). The authors state that the MBT is "the next step above the Inventory in mechanics understanding" (p. 159) and is often referred to as the problem-solving counterpart to the FCI (Hestenes & Wells, 1992; Redish & Hammer, 2009). The MBT tests on a similar list of topics in introductory mechanics, with the addition of conservation laws and energy considerations, but it is more quantitative in nature. The MBT was also developed in a similar manner to the FCI, although the multiple choice distracters are made of up common student mistakes on various problems instead of commonsense explanations as on the more qualitatively oriented FCI. However, since the MBT is meant to test students' formal knowledge of mechanics along with their problem solving skills, it is not recommended that this test be administered as a

pre-test to students just entering an introductory course, as they would likely have very little formal knowledge of physics at that point.

While the Force Concept Inventory is the most widely used test of student understanding of basic Newtonian mechanics, the Force and Motion Conceptual Evaluation (FMCE) measures a student understanding of a similar set of topics (Thornton & Sokoloff, 1998). The FMCE was developed to probe student conceptual understanding of Newtonian mechanics and allows researchers to distinguish among common student views about dynamics. The test was developed and validated based on the results of extensive interviews of students in calculus-based introductory physics classes and with university physics instructors. While the FMCE covers a similar set of topics as the FCI, instead of being organized around a set of conceptual domains in mechanics, the FMCE is organized by problem type, such as force-sled, cart on ramp, coin toss, etc. Each "type" of problem contains several questions probing different aspects of Newtonian mechanics dealing with that type. The authors state that this allows an analysis of where students are on a continuum from non-Newtonian to Newtonian thinking. The FMCE also differs from the FCI in that, while it does use a multiple-choice format, most questions require students to choose from up to nine different choices.

In addition to tests measuring student understanding of Newtonian mechanics, instruments have been developed that measure student understanding of topics in electricity and magnetism, often the focus of a second semester in introductory physics courses. These instruments, the Conceptual Survey of Electricity and Magnetism (CSEM) and the Brief Electricity and Magnetism Assessment (BEMA) are broader surveys meant to give instructors and researchers an overview of student knowledge of

these topics (Maloney, et. al., 2001; Ding, et. al., 2006). Maloney, et. al. state that it is more difficult to develop a test for electricity and magnetism that it is for mechanics for a few reasons, including that physics education research on student pre-instructional ideas on these topics is lacking, that electricity and magnetism as a domain is much broader conceptually and relies on understanding in other domains, such as force, motion, and energy, and that, unlike Newtonian mechanics, students have very little familiarity with the phenomena, language, and principles involved in electricity and magnetism before they begin their physics course.

Both tests were developed initially with open-ended questions that students were required to write detailed answers to. Alternate answers to multiple choice questions were then chosen from the most common student wrong answers on the open-ended questions. Topics included in the tests include Coulomb's law, electric force and superposition, electric and magnetic fields, and Faraday's law. The instruments have been validated and tested in a wide variety of introductory classes and statistical analyses on both surveys have shown them to be reliable measures of student understanding of electricity and magnetism topics. Maloney, et. al. recommend using the CSEM as an evaluation of instruction and as a preliminary measure of student knowledge, but caution that there is not enough information about common student alternative ideas about electricity and magnetism for the instrument to sufficiently test for this. Ding, et. al. give similar cautions about BEMA and suggest this as an area of future research.

In almost all cases of research found using these instruments to measure student conceptual understanding of physics, the Hake gain score was used to report increases, or decreases, of student understanding of physics. The Hake gain score is a calculation of

normalized gains from pre- to post-test on the FCI or other survey (Hake, 1998). The Hake gain, or "g," is calculated as the ratio of the average gain for a class to the maximum possible average gain for that class, or

$$\langle g \rangle = \frac{(\text{post \% avg.}) - (\text{pre \% avg.})}{100 - (\text{pre \% avg.})}.$$

The Hake score can be computed for individual students or for a class as a whole. Use of this normalized gain allows comparison between various populations of individual students, as well as between classes. Hake used MDT and FCI data from sixty-two introductory physics courses with over 6000 students to calculate the average gain score for classes using traditional instruction and for classes using various interactive engagement methods in order to answer the question of whether the use of interactive engagement methods significantly increased the effectiveness of introductory physics courses.

Hake's study is in large part used in the literature as a measure of the validation and reliability of the FCI. However, Coletta and Phillips (2005) suggest that the Hake gain score alone is not enough to give a complete picture of student gains in introductory physics courses. They performed a study of FCI scores for almost 3000 students in thirty-eight interactive engagement classes and found that pre-instruction scores were correlated with the Hake gain for many of the students in their sample. They say that this can be accounted for by considering differences in student populations, particularly differences in students' scientific reasoning ability, and suggest that a test of scientific reasoning, such as the Lawson's classroom test or another, be used alongside the FCI in order to more completely measure the effectiveness of instruction (Coletta & Phillips, 2005; Lawson, 1978).

Another critique of the FCI and other measures is that students may come to know that the "right" answers to the questions are without actually believing those answers or explanations themselves and report those answers instead. This is an issue of test reliability and could invalidate the results of the surveys. In order to answer this question, McCaskey, et. al. (2004) studied students in three introductory physics classes. Two of these classes were at a large, public university and one was at a small, private college and all classes were taught traditionally. Students were given the FCI as a post-instruction test, but the instructions were slightly modified. First, students were asked to complete the FCI in the standard way and hand in their answer sheets. Then, students were asked to take the test a second time. On this second pass, students were asked to give two answers to each question; they were asked to "circle the answer you really believe" and to "draw a square around the answer you think a scientist would give." They found a significant minority of students "split" in their FCI scores, with almost all student's scores of "what they think a scientist would say" to be higher than their "what you believe" scores. They also found that the number of students in their sample answering questions on the first administration of the FCI with their 'belief' answers was higher for women than for men, with men who split more often answering with their "scientist" answer on those questions. McCaskey, et. al., suggest administering the split survey task to students along with the FCI to improve the validity of the results. Redish and Hammer (2009) performed a similar analysis in a study of the impact of a fully reformed curriculum in an algebra-based introductory physics course that pays particular attention to student epistemologies. They found that students in the reformed class split much less often than students in the traditional class, which they take as evidence that paying

explicit attention to student epistemologies can help students to reconcile their beliefs with what they have learned in class. In both cases, the researchers caution that more data is needed to truly make sense of these results and that student interviews and other qualitative studies will help to provide context.

Views of Physics. More recently, physics education researchers have become interested in student beliefs about and attitudes toward physics. The Views About Sciences Survey (VASS) was developed in order to study student views about knowing and learning physics (Halloun & Hestenes, 1996). VASS can be used to study student beliefs about the nature of science and learning science along six dimensions: structure, methodology, validity, learnability, reflective thinking, and personal relevance (Halloun & Hestenes, 1998). Survey items were classified according to these dimensions by analysis by experienced physics professors. The survey items are formulated in a Contrasting Alternatives Design (CAD) that uses an 8-point scale where respondents can choose between a primary and contrary view, or a weighted combination of the two options. In order to establish a comparison for student responses, the survey was administered to college and high school physics instructors that they refer to as holding the expert view. Student answers on VASS items were then classified as either agreeing with experts, mixed, or folk. Folk views are essentially the opposite of the expert view and characterize a naïve epistemology. The mixed views are again refined into two groups: high transitional and low transitional. Students whose views are classified as high transitional are those with mixed views who agreed with the experts more than half the time, and students whose views are classified as low transitional agreed with the expert less than half the time and had more folk views than expert views. The authors

caution that student views are not necessarily coherent within any given dimension and they theorize that this is due to many introductory students not holding coherent views/epistemologies rather than a weakness of the survey itself.

Another survey that probes into student views of physics and physics learning is the Maryland Physics Expectations Survey (MPEX) (Redish, et. al., 1998). Items for the MPEX were chosen from an extensive literature review and discussions with physics faculty at several colleges and universities. These statements were then given to students in a large enrollment, introductory physics class and students were asked to rate their agreement on a 5-point Likert scale, with 1 being the student strongly agrees and 5 being strongly disagree. The items were then validated by discussion with physics education researchers, student interviews, administering the survey to a group of "experts," and repeated delivery to groups of students. The MPEX focuses on six dimensions along which to categorize student views: independence, coherence, concepts, reality, math link, and effort. Items were classified as probing a particular dimension by evaluation by physics education researchers and some items can cluster in more than one dimension. Student responses on an item are rated as favorable if they agree with the expert view and unfavorable if they disagree. As with VASS, interviews with students showed that students are not consistent with their responses to questions that seem similar to experts. However, the authors suggest that this is not a failure of the survey, but that instead student views may be situational and that self-reports may not match up with actual behavior. Also like VASS, this survey is meant to give information about a class as a whole, and is not necessarily valid for individual students. For that, the authors of both

surveys suggest that interview data is necessary (Redish, et. al., 1998; Halloun & Hestenes, 1998).

A third survey developed specifically to study student epistemologies is the Epistemological Beliefs Assessment for Physical Science (EBAPS) (Elby, et. al., 2001). The authors criticized the VASS and MPEX surveys as being too context dependent and specific to the nature of physics knowledge as viewed by students in an introductory course. They state that this may cause student expectations of learning physics in a specific class and their epistemologies, or beliefs about physics in general, can be out of alignment. This essentially agrees with the caution put forth by Redish, et. al. (1998) in their paper discussing the design and validation of the MPEX. In order to remedy this, the authors developed EBAPS items using an extensive literature review of epistemology research and used the guiding principles summarized here:

1. The survey will measure multiple dimensions of student epistemologies: structure of scientific knowledge, nature of knowing and learning, real life applicability, evolving knowledge, and the source of the ability to learn.
2. The survey will contain multiple item types: Likert scale, multiple choice, and "debate" items
3. The survey will be specific to the physical science disciplines of physics and chemistry
4. To the extent possible, the survey items will have no "obvious" answer
5. The survey will have rich contextualization in order to probe implicit epistemological beliefs

The EBAPS was then revised based on pilot studies and informal feedback as well as by administering the survey to students and asking them to explain their answers.

Elby, et. al., suggest that the EBAPS will be useful to researchers when used in addition to student interviews, case studies, and other research that probes student beliefs more deeply. They also note some issues with EBAPS that have not yet been resolved. These issues include the difficulty of entirely separating student epistemologies from classroom expectations, as well as the difficulty of separating student beliefs from goals. They also caution that it is difficult to determine the reasons that a student gives a particular response without having interview or other data and that students may learn the "correct" answers to the items and supply those, regardless of their actual beliefs.

The most recent addition to surveys of student views about physics is the Colorado Learning Attitudes about Science Survey (CLASS) (Adams, et. al., 2006). The authors argue that CLASS is different from previous surveys for many reasons, but most importantly in that it was designed to address a wider variety of issues relevant to introductory physics students and education researchers than previous surveys and that the categories or dimensions used in CLASS to group student views were in part statistically determined. The survey was developed similarly to MPEX and began with many of the same or similar statements. Those statements were then used in interviews with students in order to make them clearer and more concise and the results of interviews showed that students consistently interpreted the new statements in the same way as experts. Categories of statements were developed using a mix of predetermined categories based on extensive reviews of the literature and factor analysis. The authors

argue that this approach leads to categories that are meaningful to both students and researchers and statistically robust.

One criticism of MPEX and EBAPS has been that student responses are not necessarily internally consistent (Adams, et. al., 2006; Elby, et. al., 2001; Redish, et. al., 1998). While Redish, et. al. (1998) theorize that this is not a problem because it shows that students' ideas about learning are not always consistent, Adams, et. al. (2006) make the argument that by submitting their pre-determined categories to a factor analysis, ideas such as sense making and effort are shown to be linked in student minds, even when those statement types do not seem to be related for experts. They say that their approach leads to categories that are both useful to researchers and statistically robust and that are supported by student interview data. The categories used in the CLASS are personal interest, real world connections, conceptual connections, sense making/effort, problem solving, and applied conceptual understanding. During studies of the validity and reliability of CLASS, Adams, et. al. (2006) also asked students to complete McCaskey, et. al.'s (2004) split-survey task using the CLASS. They found that students could readily identify the expert responses and that many students' responses were split even after instruction with reformed curricula, but that in almost all cases, student responses to the first administration of the CLASS matched with their responses to the "what do you really believe" question. They argue that this is evidence for the validity of the CLASS.

Qualitative Methods for Measuring Student Learning

Although most physics education research found is quantitative in nature, there are also studies with qualitative elements. In particular, the development of the surveys previously discussed involved references to extensive interviews with students and

physics faculty to determine the nature of student views and misconceptions, as well as determining the particular concepts and attitudes deemed most important to learning of introductory physics by physicists and educators. Unfortunately, none of the research discussing the development of quantitative survey instruments reported details of the qualitative methods or the development of codes used in analyzing data, etc. However, there has been a more recent trend toward qualitative studies among physics education researchers working specifically in the area of student learning in college and university introductory physics courses. The next section of this review will be dedicated to the discussion of a few of the more recent and detailed of these.

May and Etkina (2002) used qualitative methods in their study of the relationship between introductory physics students' self-reflection skills and conceptual learning. To measure student conceptual learning during the course, they administered the FCI, MBT, and CSEM as pre- and post-tests. To measure students' self reflection skills, they asked students to complete a Weekly Report during the course of the two-semester class that included questions about what they learned during various aspects of the class, how they learned it, and what topics the students felt confused or unclear about. They used the Weekly Reports because the context of a written assignment is different than in an interview, although they suggest that interviews can be used to verify the content of the Weekly Reports or for probing the context dependence of student epistemological beliefs.

Student responses on the Weekly Reports were coded based on what students said they learned, how they said they learned it, and inferences that could be made about students' views of the nature of physics knowledge. The codes are summarized as follows:

1. What students say they learned
    a. formulas
    b. vocabulary
    c. concepts
    d. skills
2. How they say they learned
    a. observed phenomena
    b. constructed the concept from observation
    c. reasoned/derived in lecture
    d. learned by doing
    e. authority
    f. predicted/tested
    g. predicted/tested/interpreted
3. Inferences about views
    a. applicability of knowledge
    b. concern for coherence

They also rated the codes in the last two categories as favorable or unfavorable based on the learning goals of the course. For example, student learning from authority is rated as unfavorable, while student learning from reasoning or derivation is rated as favorable. For some of the codes, like applicability of knowledge, the favorable or unfavorable rating was determined from the context of the student's statement. For each student, researchers added up the number of code indications, or the instances of assigning a code to a sentence, group of sentences, or idea in a report. In order to control for the length of

student answers, the code indications were then normalized by dividing the total number of indications for a code in a response for the total number of indications for that student. They also checked the inter-rater reliability of their codes by having the researchers all code the statements from a small selection of students. It was found that in all instances, different researchers agreed on the codes to be used in a particular Weekly Report and they agreed on the number of indications for each code over 90% of the time.

In another study, Lising and Elby (2005) presented a case study of a single student in the second semester of introductory physics. The purpose of this study was to investigate the influence of epistemology on learning. They used video of a small group of students working on tutorial tasks and interviews with a single student in the group about her reasoning on various tutorial topics. The interviews' stated purpose was to see if she truly understood a topic and to observe her reasoning about various phenomena to gain information about her epistemological beliefs. During the course of the interviews, the student was given thirty six problems in five interviews and data was coded according to two broad categories: the line of reasoning used by the student and whether or not a conflict or lack of connection between two lines of reasoning was reconciled. These two categories were then divided into subcategories:

- Line of reasoning: Did the student use formal or informal reasoning or a combination of both?
- Reconciliation of conflict: Was the reconciliation of conflicting ideas between lines of reasoning of the same type (coded as within type) or of different types (coded as between type)?

The reliability of the coding was checked by asking researchers not previously involved in the study to apply the codes to a subset of interview and video data. The external coder's results agreed with the researchers 80% of the time.

Turpen and Finkelstein (2009) compared the implementation of Peer Instruction by instructors of different introductory physics classes. To do this, they approached their study from an ethnographic perspective and collected data in the form of extensive observations of classroom practice, audio recordings of classes, and interviews with instructors. They also used a hierarchical model to describe classroom norms, stating that "collections of observable characteristics of practice make up dimensions of practice (DoP), and combinations of DoPs make up classroom norms" (p. 3). The purpose of the development of the DoP is to assist observers to link instructor choices and actions to the creation of classroom norms and expectations. In order to create a framework for the dimensions of practices, they focused on instructor practices that they felt would influence student learning outcomes in terms of conceptual understanding, epistemology, attitudes about learning, and scientific abilities. The first draft of the DoP was based on preliminary classroom observations and a review of the literature. They organized their final list of thirteen dimensions of practice into two categories: defining the academic task and student-professor interactions. They also created an observation rubric based on preliminary observations of classroom practice. The purpose of the rubric is to aid the observer in categorizing various instructor and student interactions during Peer Instruction according to the various DoP. The rubric breaks each period of Peer Instruction into three stages, the question set-up stage, the question response stage, and the question solution discussion stage, and provides guidance on keeping notes on what

the instructor and students do during each stage. It also includes space for descriptions of the specific questions asked and distributions of student answers. In addition, the rubric guides the observer in the creation of a diagram representing classroom discussions in terms of how many students participate and who references or responds to whom during these interactions. Finally, they present their data analysis and results as summaries of implementation for all professors across the Peer Instruction stages, as summaries for each professor involved, and as case studies of the two most extreme implementations in terms of the numbers or questions asked and the extent of instructor-student interactions during Peer Instruction.

Redish and Hammer (2009) performed a mostly quantitative study of the effectiveness of a completely redesigned introductory physics course on increasing student conceptual understanding and improving student views toward physics. They administered both conceptual and attitude surveys, but in order to add context to their survey data, they also collected other data in the form of student homework, laboratory reports, and exams, video of students participating in laboratory and tutorial sessions, and extensive interviews with several students both at the beginning and end of each term. They provided information about their data analysis for the videos of student interactions in laboratory. In this analysis, Redish and Hammer coded student conversations and statements according to the following four categories:

1. Sense making: Are students connecting laboratory activities to a sense of physical mechanisms?
2. Logistics: Statements concerning how to proceed with the activity that do not specifically reference physics concepts.

3. Off task: Statements that are not relevant to the task at hand.
4. Megacognitive: Statements expressing feelings or an evaluation of feelings about some aspects of understanding of concepts. (p. 12).

They used these codes to characterize student statements and conversations while participating in laboratory activities and then used a time-block plot to show the amount of time during the two hour laboratory class that students spent on conversations in each of the first three of these categories, with metacognitive statements overlaid onto the plot.

Discussion of Research Instruments

Although qualitative methods remain relatively uncommon in physics education research, it is becoming more prevalent as researchers become more interested the details of student understanding and comparing the implementation of various instructional reforms. The reasoning given for most qualitative methods used, however, is to give context and depth to survey data, or to validate the results of quantitative research. McDermott (1984) suggested a framework that should be considered when performing and interpreting the results of physics education research. Included in this framework are considerations of the nature of the instrument used, the degree of interaction between researcher and subjects, the depth of probing (surveys vs. written responses vs. interviews), the physical setting of the research, and the goals of the investigator. Physics is by its nature an empirical science and it is not surprising that many physics education researchers, who are physicists themselves, would prefer a more quantitative approach to research. However, this preference is balanced by the need to develop reliable and statistically valid survey instruments, to provide context to quantitative data, and to provide detailed information about the extent or nature of a phenomenon.

Chapter Four

Methods

The purpose of this study is to investigate whether the use of interactive engagement strategies in a large enrollment, lecture-based college physics course can lead to increased student learning of physics concepts and student views of physics that are more consistent with physicists'. Some limitations to the large enrollment, lecture-based course that can impede student learning include the lack of one-on-one interaction between students and instructors and the lack of individual feedback to students. This study will investigate the extent to which the use of interactive engagement can overcome these limitations. Interactive engagement (IE), as defined in the literature, consists of a set of strategies that are designed to promote students' conceptual understanding through activities that require them to be actively engaged with the course material and to interact thoughtfully with each other and the instructor around physics concepts through discussion about their thinking and learning. These strategies have been used successfully to increase student conceptual understanding of physics in large, lecture-based classes that also have a smaller recitation component. However, no work has been found studying these strategies in large, lecture-based classes with no separate recitation component.

Overall Approach

The study is a mixed methods study, with both qualitative and quantitative components. The use of a quantitative approach, with pre-post testing of student conceptual understanding of physics and students' views of physics, allows measurement of how much students have learned and how their views about physics change over the

semester. This approach is augmented with repeated interviews of a few students throughout the semester to allow investigation of which features of the course design contribute the most to student learning of physics and students' views about physics. The research takes place in a large enrollment, lecture-based physics course that is taught using interactive engagement. The research questions for this study are

- What do students learn about physics concepts and how does student learning in this course compare to that reported in the literature for students in a traditional college physics course?
- Do students' views about physics change and how do students' views compare to that reported in the literature for students in a traditional college physics course?
- Which of the instructional strategies contribute to improved student conceptual understanding and more physicist-like views of physics in this course?

According to educational research, students learn physics best when they are encouraged to construct their own understanding of concepts in an environment that allows for student cooperation and communication about the topic at hand (NRC, 2000). This environment allows for the development of aspects of student thinking, including students sharing and integrating their ideas about physics, justifying their reasoning, and applying their understanding to solving problems. It allows the course to be designed to provide for certain instructional opportunities that lead to student thinking, including providing opportunities for students to interact with their peers and with physics phenomena, increased instructor guidance, making student reasoning visible, and revision of student ideas. These make up a set of instructional strategies that will be used to guide

the research: indications of student thinking and instructional opportunities. The instructional strategies are defined in Table 1.

Table 1

Defining the Instructional Strategies

Instructional Strategies	Definition
Aspects of Student Thinking about physics	
1. Share ideas	Students talk to each other and share their ideas about physics concepts.
2. Integrate ideas	Students think about how physics concepts fit together.
3. Justify reasoning	Students are able to explain why they answer a question a certain way and to defend their answers using clear and logical reasoning.
4. Apply reasoning	Students are able to apply their understanding of concepts to solve problems.
Instructional Opportunities in physics	
5. Interaction with peers and with physics phenomena	Students work together to discuss their ideas about physics, to develop their conceptual understanding, and to work through problems.
6. Instructor guidance	The instructor provides students with re-direction, hints, coaching, modeling, and feedback about student work.
7. Making student reasoning visible	Students' reasoning is made visible to the students themselves, other students, the class as a whole, and to the

	instructor.
8. Opportunities for revision	Students are given explicit opportunities to question and re-think their ideas and understanding of physics concepts.

Student learning of physics concepts and views of physics are measured by this study. The course focuses on Newtonian mechanics, particularly kinematics, dynamics, and thermal physics, although only kinematics and dynamics are included in this research. Although the course includes many more topics, this study focuses in depth on student learning of a few concepts chosen specifically because students often have particular difficulty with understanding and reasoning through problems dealing with them. The concepts are listed in Table 2.

Table 2

Physics Concepts

Topic	Physics Concept
Kinematics	Motion in One Dimension—discriminating position from velocity and velocity from acceleration
	Motion in Two Dimensions—relating acceleration to changes in velocity
Dynamics	Net force and Newton's second law
	Force and acceleration in one dimension—gravity and falling
	Collisions and Newton's third law—equal and opposite forces
	Net force and Newton's third law

In addition to physics concepts, the study will measure how students' views of physics change over the course of the semester, particularly in the categories of value, effort, confidence, connectedness, and applicability. Student views of physics include how students value physics and how they think about physics as a subject. The category names are simply shorthand for the general values contained within them. The categories of student views are defined in Table 3.

Table 3

Views of Physics Defined

Views of Physics	Definition
Value	Students value physics, understand the usefulness of physics, and find it interesting.
Effort	Students are willing to make the required effort to learn physics.
Confidence	Students have confidence in their ability to do physics, learn physics, and solve problems.
Connectedness	Students see a relationship between ideas in physics.
Applicability	Students see that physics concepts can apply to real world problems.

Background

Participants. The study took place in an introductory college physics class in the fall semester of 2012. The class began with 146 registered students, and of these, 93 students completed both the pre- and post-tests of student content knowledge and views of physics and all items on the demographic survey. Of the 53 students who did not

complete the pre- and post-tests and demographic study, 19 dropped the course entirely and the rest simply did not complete all of the items used for data analysis, so they were not included in this study. The participants included in the study are the 93 students for whom a complete data set is available. The participants were approximately 50% male and 50% female, with 46 males and 47 females. The participants had an average age of 20.65 and were on average in their third year of school. More than half the students (53) had taken physics in high school, with a further 13 students having had a previous college physics class. The rest had no previous physics experience. The majority of students in the class had declared majors in a healthcare related field, with the three most popular being pre-pharmacy, pre-physical therapy, or athletic training, and pre-medicine. The remaining students declared majors in other sciences (biology, chemistry, or an engineering field) and one student majored in a non-science field. Demographic data for the class is summarized in Table 4.

Table 4

Number of Participants by Gender, Age, Year in School, Previous Physics Classes, Major, and Race/Ethnicity

Demographic Category	Number of participants (n=93)
Gender	
Male	46
Female	47
Age	
18	1

19	20
20	28
21	21
22	10
23+	13
Year in School	
Year 1	1
Year 2	35
Year 3	30
Year 4	14
Year 5 or more	13
Previous Physics Class	
No previous physics	27
Only high school physics	53
Previous college physics	13
Major	
Pharmacy	31
Pre Medicine	16
Biology	11
Physical Therapy	26
Nursing	1

Chemistry	3
Other Science	4
Other non-Science	1
Ethnicity	
White	73
Asian	3
Indian/South Asian	1
African American	9
Hispanic	2
African	2
Middle East	2
Native American	1

The course. The study took place in the first semester (16 weeks) of a two-semester, large enrollment, lecture-based college physics course, General Physics I, at a mid-sized public university in the Midwest. There are two sections of General Physics I offered every fall—a traditionally formatted morning course and a lecture-based evening course. This study took place in the lecture-based evening section. The class met twice a week in the evening, for two hours each meeting, and has a laboratory component that is treated as a separate course. There is no separate recitation section for this course.

The course was taught using the IE strategies of Peer Instruction, interactive demonstrations, and tutorials. These strategies are all designed to increase student interaction with each other and with physics phenomena, make student reasoning explicit

and visible to both students and instructors, provide students with opportunities to revise their thinking, and increase instructor guidance and feedback to students.

Peer instruction questions using clicker technology were incorporated into every class session. In Peer Instruction, the lecture is stopped periodically to ask students challenging conceptual questions. Students are first asked to consider a question individually, formulate an answer, and "vote" for their choice using the clicker technology. If more than approximately 75% of students answer correctly, the instructor reveals the results of the vote, prompts a class discussion of the correct answer by soliciting student reasoning and explanations, and moves on to the next topic or question. If fewer students answer correctly, students are asked to break into groups of two or three students and discuss their ideas, working together to revise their ideas and agree on a solution. After several moments of small group discussion, during which time the instructor circulates through the class answering questions and prompting student discussion, the class votes again. After the second vote, the instructor leads a whole class discussion of the students' reasoning about the physics concepts being investigated. This sequence of question-answer-discussion-answer occurs several times during each class meeting.

Interactive demonstrations are incorporated into the class session at least once a week. Interactive demonstrations follow a predict-observe-explain format using the clicker system. First, the demonstration is set up and the instructor solicits student predictions about the results of the experiment during class discussion. Students are then asked to break into small groups of two or three students and discuss their predictions for the results of the demonstration before polling with the clicker system, with student ideas

used as some possible choices in the student poll. After the polling, the instructor performs the demonstration and, based on the results of the class polling and demonstration, prompts a class discussion about the results. These activities allow students to interact with each other and with physics phenomena, as well as revise their ideas about how the physical world works.

Tutorials are incorporated into the class session approximately once a week. Tutorials are longer activities based around developing students' conceptual understanding of particular concepts and take between 30 minutes and one hour to complete. Students work in groups of two or three to complete a set of questions and activities that introduce a concept and require students to think through progressively more difficult applications of the concept, constantly revising their ideas. Students are also explicitly required to explain their reasoning about a question in detail, both in writing and to each other, as they complete the tutorial. The tutorials used are based on the Open-Source Tutorials in Introductory Physics from the University of Maryland and the Tutorials in Introductory Physics from the University of Washington Physics Education group (Scherr & Elby, 2007; McDermott & Shaffer, 2001). Any modifications that are made to these existing tutorials to facilitate their use in a stand-alone, lecture-based course are noted. The mapping of specific features of the course design to the instructional strategies and measures is summarized in Table 5.

Table 5

Instructional Strategies Mapped to Course Features and Measures

Instructional strategies	Course Design	Measures
Indications of Student Thinking		

Share ideas	*Peer Instruction*: Students work in groups and discuss their reasoning and answers to conceptual questions *Interactive demonstrations*: Students work in groups and discuss their predictions and the actual results of the experiment *Tutorials*: Students work in groups and discuss their answers and reasoning about tutorial questions	Interviews Student surveys Student Tutorials
Integrate ideas	*Peer Instruction*: Students discuss their preliminary ideas and answers to conceptual questions with each other before settling on a 'final vote.' *Interactive demonstrations*: Students discuss their preliminary predictions with each other before the demonstration and must reconcile their prediction with the results of the experiment. *Tutorials*: Students are explicitly guided through revision and integration of their original ideas in tutorial questions.	Interviews Student surveys Student Tutorials
Justify reasoning	*Peer Instruction*: Students discuss their	Interviews

	reasoning about conceptual questions with each other during small group discussions. *Interactive demonstrations*: Students discuss and justify their predictions with each other before the demonstration. *Tutorials*: Students write out their explanations and reasoning for tutorial questions and discuss their reasoning in groups.	Student surveys Open-ended exam questions Student Tutorials
Apply reasoning	*Peer Instruction*: Students use their understanding of physics concepts to answer progressively more difficult conceptual questions. *Interactive demonstrations*: Students use their understanding of physics concepts to predict and explain the results of experiments. *Tutorials*: Students develop their understanding of concepts and solve problems and answer questions.	Interviews Student surveys Open-ended exam questions Student Tutorials
Instructional Opportunities		
Interaction with	*Peer Instruction*: Students work in groups	Interviews

peers and physics phenomena	and discuss their reasoning and answers to conceptual questions *Interactive demonstrations*: Students work in groups and discuss their predictions and the actual results of the experiment *Tutorials*: Students work in groups and discuss their answers and reasoning about tutorial questions	Student surveys
Instructor guidance	*Peer Instruction*: Instructor leads whole class discussion and provides feedback to small group discussions *Interactive demonstrations*: Instructor sets up and explains demonstration, leads class discussion, and provides feedback to small group discussions *Tutorials*: Instructor provides feedback to small group discussions and models correct reasoning	Interviews Student surveys
Making student reasoning visible	*Peer Instruction*: Students discuss their preliminary ideas about conceptual questions with each other and student final answers are shown to the class. *Interactive demonstrations*: Students	Interviews Student surveys Open-ended exam questions

	discuss their preliminary predictions and student final predictions are shown to the class. *Tutorials*: Students are explicitly required to write out their explanations and reasoning for tutorial questions and asked to discuss their reasoning in groups.	
Opportunities for revision	*Peer Instruction*: Students discuss their preliminary answers and ideas about conceptual questions with each other before the final "vote." *Interactive demonstrations*: Students discuss their preliminary predictions with each other before the demonstration and must reconcile their prediction with the results of the experiment during group discussions and whole class discussion. *Tutorials*: Students are explicitly guided through revision of their original ideas in tutorial questions.	Interviews Student surveys

Instruments

Demographic survey. Demographic data was collected on students in order to investigate whether student demographics matched to improvement in student understanding of physics or student views about physics. This included data on student gender, race and ethnicity, year in school, major, and previous physics courses. The demographic survey consisted of a free-response set of questions and was administered during the first week of class.

Physics content knowledge. Student conceptual understanding of physics was measured with the Force Concept Inventory (FCI) (Hestenes, et. al., 1992). The FCI is a 30 question multiple-choice test designed to probe student conceptual understanding of common topics in Newtonian physics. The test forces students to "choose between Newtonian concepts and common sense alternatives" (Hestenes, et. al., 1992, p. 142). The FCI is one of the oldest and most widely used tests of student conceptual understanding in physics education research.

Student understanding of physics was also measured through the use of open-ended questions that are embedded in three class exams throughout the term. These questions were more in-depth and focused on student reasoning about physics concepts. The questions used for each of the main topical areas in the course (kinematics and dynamics), along with corresponding FCI categories and scoring rubrics for each are attached in Appendix A. The topics were chosen to match topics that are reported in the literature to cause particular student difficulty. They also match both the list of topics available on the FCI and available tutorials.

Views of physics. Student views about physics were measured by the Colorado Learning Attitudes About Science Survey (CLASS) (Adams, et. al., 2006). The CLASS is a 42-item, Likert-type survey with questions that probe students' views about physics and learning physics. The CLASS is set up in such a way that student responses do not necessarily need to be internally consistent across the set of questions in order for the survey results to be valid (Adams, et. al., 2006). Table 6 shows CLASS items matched with the views about physics categories defined in Table 3. Some statements in the CLASS survey are not scored or do not correspond to the particular categories of student views that are of interest in this study. Attached in Appendix C is a copy of the CLASS survey.

Table 6

Categories of Student Views of Physics Matched to CLASS Statements

Views of Physics	CLASS Statements
Value	3, 11, 14, 25, 28, 30,
Effort	11, 23, 24, 32, 36, 39, 42
Confidence	15, 16, 34, 40
Connectedness	1, 5, 6, 8, 13, 21, 22, 32, 40
Applicability	28, 30, 35, 37

Fifteen students were invited to also participate in periodic interviews investigating students' views of physics in more detail than the CLASS survey. These interviews were given three times during the semester, during the week before each of the class exams. Students were chosen for interviews based on their CLASS pre-test scores,

with five students with highly favorable CLASS pre-test scores, five students with overall neutral CLASS pre-test scores, and five students with highly unfavorable CLASS pre-test scores invited to participate. Of these, two of the initially favorable students, all five of the initially neutral students, and three of the initially unfavorable students completed all three interviews. The interview questions about students' views of physics, along with possible follow-up questions, are summarized in Table 7.

Table 7

Interview Questions About Student Views of Physics

What do you think about physics as a subject (not the course)? • Do you find physics interesting? • Do you feel like learning physics will be useful to you outside of class? • Do you feel like physics knowledge is useful in the wider world?

Describe your approach to studying physics or doing physics homework.
• How important is memorizing information to your studying?
• How much time do you spend thinking about concepts when you are solving a problem?
• For first interview:
  o Do you feel like you can use the concepts you are learning now later in the semester?
• For later interviews:
  o Do you feel like you are still using concepts from earlier in the semester or does it all seem new?

How confident are you in your ability to learn physics?

- What do you do if you can't figure out a problem or question or if you get stuck?
- What do you do if you get an unexpected result on a problem or if your answer doesn't make sense?

Instructional strategies and course design. In addition to interview questions on student views of physics, students participating in interviews were also asked about which of the features of the course design contributed to their learning of physics concepts and their views about physics. Students who were not invited to participate in interviews were instead invited to answer open-ended surveys on the various features of the course at three different points in the semester, during the same weeks as the interviews. The interview questions on course design were used in these written questionnaires to investigate student perceptions of the usefulness of the course design and which of the instructional strategies they felt most contributed to learning. The interview and open-ended survey questions about course design are summarized in Table 8.

Table 8

Interview and Open-ended Survey Questions About Course Design and Instructional Strategies

Interview Questions and Follow-ups
Are there any aspects of the in-class activities that you found helpful to learning or understanding physics concepts?

- When was it helpful to work together and share ideas with other students?
- When was it helpful to explain your reasoning on questions or problems in writing or verbally in groups?
- When was it helpful to re-think or revise your ideas about concepts or how things work?

Are there any aspects of the in-class activities that you felt did not help or made it harder to learn physics?

- Were there times when you thought working together during class made learning physics harder?
- Were there times when explaining your reasoning on questions or problems in writing or verbally in groups made learning physics harder?
- Were there times when re-thinking or revising your ideas about a concept made learning physics harder?

Is there anything about the in-class activities that you would change?

Is there anything about the in-class activities that increased your enjoyment of physics (as a subject) or your feelings about the usefulness or applicability of physics you have learned to your everyday life?

- Did working together and discussing your ideas increase your enjoyment of physics or your feelings about its applicability?
- Did having opportunities to revise your ideas or explain your reasoning increase your enjoyment of physics or your feelings about its applicability?

Open-ended Survey Questions

Are there any aspects of the in-class activities (working in groups, sharing ideas, explaining your reasoning in writing/verbally, etc.) that you found helpful to learning or understanding physics concepts?

Are there aspects of the in-class activities that you felt did not help or made it harder to learn physics?

Is there anything about the in-class activities that you would change?

Is there anything about the in-class activities that increased your enjoyment of physics (as a subject) or your feelings about the usefulness or applicability of the physics you have learned to your everyday life?

Data Collection

The FCI and CLASS were administered to students at the second class meeting of the semester (pre-instruction) and again during week 13 of the semester (post-instruction). The FCI and CLASS surveys were administered using printed questionnaires and a scantron sheet. The demographic survey was administered on the same days as the FCI and CLASS surveys, after students had finished. The demographic survey was administered using a printed questionnaire and students were asked to write their responses directly on the sheet. Three midterm exams were given during the semester, during weeks 4, 8, and 12. Each exam contained an open-ended questions about the conceptual topics covered in the course and based on in-class activities. The questions and scoring rubrics are listed in Appendix A. Student interviews and the open-ended questionnaires took place within one week before each exam.

Data Analysis

Physics content knowledge. FCI items were scored overall and in categories corresponding to the physics content areas of kinematics, Newton's 2nd law and forces (dynamics 1), and Newton's 3rd law and momentum (dynamics 2). Student pre- and post-test scores on the FCI were computed and used to calculate normalized gain scores for each student overall and in the various categories of the FCI. Normalized gain, g, is a measure of gain divided by the maximum gain, which allows a comparison between students that is independent of pre-test score. Normalized gain is commonly used in physics education research and will allow a comparison with the literature. It is calculated by the following formula:

$$g = \frac{post - pre}{100 - pre} \quad (1)$$

The scores were compared for different demographic groups to see if there were any trends in the data for student gender, race, major, etc. FCI pre- and post-test scores and gains for each student and for the class as a whole were broken down according to the physics content categories (kinematics, dynamics 1, and dynamics 2). In addition, the open-ended items on the course exams were analyzed according to the scoring rubrics summarized in Appendix A and compared for the demographic groups. Since these items were placed after instruction for the various categories, scores were also compared with the FCI post-test scores in the corresponding categories to check for consistency and growth for each student. The exam data was coded and rated for student reasoning and correctness of student answers and compiled according to student scores on individual items and an overall score for the exams. This data was compared to student FCI scores

on questions dealing with the same topics as the exam questions and overall in order to investigate whether or how FCI gains corresponded to student scores on exam questions.

Views of physics. CLASS pre- and post-test data were compared for different demographic groups to see if there were any trends in the data with student gender, race, major, etc. CLASS scores were also analyzed for each student and for the class as a whole to investigate changes in scores over the semester overall and in each category of student views, as listed in Table 3.6. Student answers to interview questions about their views of physics were analyzed according to the views of physics categories to look for consistency with the CLASS data and to check for emerging patterns. Since the interview questions remained the same across the three interviews, this data was also analyzed to check for change over time and trends in student views of physics over the course of the semester and to provide more detail and context to the CLASS data. The coding scheme used for the interview questions on student views of physics is provided in Appendix D. The interview data was also compared to the CLASS scores for the individual students to see how the students in the various strata (overall favorable, neutral, and unfavorable) in the CLASS pre-test data changed their views over the course of the semester and to look for trends in this data.

Instructional strategies and course design. Information about the various course design features and instructional strategies were collected from the interview data and student responses to the questionnaires on course design, as well as collected tutorials. Student responses on both measures regarding which aspects of the course design and instructional strategies were most and least useful and what suggestions students had for improvement were collected and tallied according to the most common

comments and ideas. In addition, student responses to interview questions on course design and instructional strategies were categorized according to students' responses as favorable, unfavorable, or neutral regarding which of the instructional strategies were helpful or unhelpful to their learning. Tutorials were coded according to how well students justified their reasoning, integrated ideas, and explained their reasoning. Collected tutorials and their coding schemes are attached in Appendix B.

Comparison across data. The FCI pre- and post-test scores and normalized gains were compared to student pre- and post-test scores on the CLASS overall and in the views categories. These comparisons were used to help determine whether student content knowledge matched to student views of physics. Student scores on the FCI were also compared to student interview and questionnaire data on course features in order to determine if student understanding of physics corresponded to student perceptions of the course features. The pre- and post-test CLASS data and interview data on student views of physics were also compared to the interview data on course features in order to determine if student views of physics corresponded to student perceptions of the course features and instructional strategies, as well as to student tutorial scores. This allowed and investigation of which of the instructional strategies contributes to student understanding of physics concepts and views of physics.

Chapter Five

Findings

The purpose of this study is to investigate whether the use of interactive engagement strategies in a large enrollment, lecture based college physics course can lead to improved student conceptual understanding and more expert-like views of physics. In addition, this study investigates which of the instructional strategies contributes to improved student understanding of physics and more expert-like views of physics.

Participants completed a demographic survey, a test of conceptual understanding, the Force Concept Inventory (FCI), and a survey of their views of physics, the Colorado Learning Attitudes About Science Survey (CLASS). The FCI and CLASS were administered both pre- and post-instruction. In addition, examples of student work in the form of tutorials and long form problems on three midterm exams were collected at various points throughout the semester. Based on pre-test CLASS scores, some students were invited to participate in interviews about their views of physics and the instructional strategies at three times during the semester. Students who did not participate in interviews were invited to complete three open-ended questionnaires about the instructional strategies. Questionnaires were given at three times during the semester.

This chapter will begin with findings for student content knowledge and student views of physics. Lastly, results will be compared across categories to investigate which of the instructional strategies contributes the most to improving student conceptual understanding and views of physics for this class.

Student Learning and Views About Physics

Physics Content Knowledge. Results of the FCI pre and post tests and normalized gains were calculated for the class as a whole and also tested against demographic data for students in the class to check for any relationships. The average normalized gain, <g>, of 32% for the class overall is consistent with a medium <g> interactive active engagement class (Hake, 1997). There was a slight, but significant, correlation between student gender and FCI pre-test scores (r=.304, p=.003), with males scoring higher than females. A similar result was seen with the FCI post-test data (r=.332, p=.001) and normalized gains (r=.206, p=.045), although this relationship is weaker. Table 9 shows the mean score for the FCI pre- and post-tests and normalized gains by gender.

Table 9

FCI Pre and Post Test Scores Organized by Gender of Participant

Test	M (%)	SD	Range
FCI Pre-test			
Male (n=46)	33.3	11.63	10 to 60
Female (n=47)	26.67	11.82	7 to 57
Overall (n=93)	29.96	12.13	7 to 60
FCI Post-test			
Male (n=46)	56.67	18.42	17 to 90
Female (n=47)	46.4	19.85	17 to 90
Overall (n=93)	51.58	19.71	17 to 90
Average Normalized Gain <g>			
Male (n=46)	35.3	25.8	-31.6 to 84.2
Female (n=47)	38.6	23.5	-10.5 to 77.8
Overall (n=93)	31.9	24.8	-31.6 to 84.2
Absolute Gain (G)			
Male	23.3	16.7	-20 to 53
Female	19.9	14.8	-7 to 60
Overall	21.6	15.8	-20 to 60

FCI questions were categorized according to topic and matched with their similarity to the topics tested on exam questions (Hestenes, et. al., 1992). The kinematics 1 group consists of questions similar in nature and topic to exam 1, the dynamics 2 group consists of questions similar in nature and topic to exam 2, and the dynamics 3 group consists of questions similar in nature and topic to exam 3. Student scores on the three exam questions spaced throughout the semester and the FCI content group questions were also tested against demographic data for students in the class. No significant correlations were found between any demographic group and student exam scores, so those results are reported for the group as a whole. Average scores in each of the FCI content categories are listed in Table 10 and exam question scores are listed in Table 11.

Table 10

FCI Pre- and Post-test Scores in Content Categories

Test (n=93)	M (%)	SD	Range
FCI Pre-test			
Kinematics 1	39.4	29.1	0 to 100
Dynamics 2	22.6	14.9	0 to 60
Dynamics 3	27.6	20.0	0 to 67
FCI Post-test			
Kinematics 1	57.7	31.9	0 to 100
Dynamics 2	50.0	19.8	0 to 100
Dynamics 3	36.0	23.0	0 to 100

Table 11

Participant Exam Scores

Exam (n=93)	M (%)	SD	Range
Exam 1 (kinematics)	66.9	21.9	0 to 100
Exam 2 (dynamics)	54.8	18.2	0 to 100
Exam 3 (dynamics)	56.4	18.0	22.2 to 100

Note that students scored higher on the kinematics questions, both on the FCI and exam 1, than on the dynamics questions. Students scored lower on the post-test in the dynamics 3 category on the FCI, which tested students' understanding of Newton's 3rd Law and matched in topical area to exam 3. The lower post-instruction scores in this area are not surprising, since Newton's 3rd Law has been acknowledged by physics education researchers as a topic that presents particular difficulties for students (Hestenes, et. al., 1992, Clement, et. al., 1989, McCloskey, 1983). On the exams, however, students scored nearly the same on both the exam 2 and exam 3 questions. Both of these examined students' understanding of Newton's Laws, although exam 2 focused mostly on Newton's 2nd Law and exam 3 focused on Newton's 3rd Law and momentum.

Individual exam scores were then tested against FCI scores in topic categories, both for the FCI pre- and post-tests. Exam scores were only slightly correlated to FCI pre-test scores in the corresponding categories, but were moderately correlated to FCI post-test scores in the corresponding categories. The FCI post-test correlations were also significant. The results of these tests are summarized in Table 12.

Table 12

FCI Post-test Scores Categorized and Correlated to Exam Scores

FCI Category	Exam	Correlation
Kinematics 1	Exam 1	0.321*
Dynamics 2	Exam 2	0.354*
Dynamics 3	Exam 3	0.318*

Note. n=93

*$p < 0.05$

Exam 2 and 3 scores were only significantly correlated with the FCI post-test scores in their respective content categories. This makes sense because the FCI pre-test occurred before any instruction, but both the exams and the FCI post-test occurred after

instruction. Exam 1 scores were correlated with both the FCI pre-test ($r=0.295$, $p<0.05$) and post-tests. This could be due to the fact that exam 1 occurred very early in the semester or it could indicate that students were more familiar with kinematics concepts before they began the physics course. That the student scores were high both pre- and post-instruction on the FCI in this content category, as well as the higher scores on exam 1, lends support to the idea that students began the course with more familiarity with kinematics concepts than with dynamics concepts.

In order to investigate whether there was a difference in FCI normalized gains and exam scores based on students' FCI pre-test scores, students were split into two groups based on pre-test scores. The lower scoring group had pre-test scores below 40% and the higher scoring group above 40%. The cut-off value of 40% was somewhat arbitrarily chosen to match similar analysis reported in the literature (Coletta & Phillips, 2005; Lasry, et. al., 2008). There was a significant difference in FCI normalized gains and exam scores for the groups and many more students fell into the low pre-test group than into the high pre-test group, with the lowest pre-test score being 6.7% and the highest pre-test score being 60.0%. This analysis is reported in Table 13 and figures 1 and 2

Table 13

FCI Normalized Gains and Exam Scores, Organized by FCI Pre-test Score[a]

Test	M(%)*	SD	Range
FCI Normalized Gains <g>			
	46.2	28.5	-11.8 to 81.3
High Pre (n=23)			
Low Pre (n=70)	27.2	21.6	-31.6 to 84.2
Exam 1			
	74.2	20.2	25 to 100
High Pre (n=23)			
Low Pre (n=70)	64.3	22	0 to 100
Exam 2			

High Pre (n=23)	63.8	19.9	33.3 to 100
Low Pre (n=70)	51.8	16.7	0 to 88.9
Exam 3			
High Pre (n=23)	63.4	15.7	33.3 to 100
Low Pre (n=70)	54.4	18.2	22.2 to 100

[a] A high pre-test score was considered as above 40% and a low pre-test score was considered as below 40%
*$p<0.001$ in all cases

Students with FCI pre-test scores greater than 40% showed significantly higher normalized gains in FCI score and higher exam scores than students who scored 40% or below on the FCI pre-test. This suggests that students in the high pre-test group may have been better prepared for introductory physics, although there was no correlation between these data and student previous physics experience, either in high school or college. According to Coletta and Phillips (2005), students' formal reasoning ability, as measured by the Lawson Test of Scientific Reasoning, was correlated with student FCI gains and they suggest that this may be a good diagnostic of student preparation for introductory physics.

Views of Physics. A similar analysis was done with the CLASS data as with the FCI. The CLASS survey consists of 42 questions, and 38 of those scored. One of the non-scored items is used as a test to see if students are answering randomly. Students are directed to give a specific response and if that response is given, the students' score is used in analysis, otherwise that students' score is not used. The other three items were discovered by the writers of the CLASS to have no clear expert or non-expert answer and so are not scored in their current form (Adams, et. al., 2006).

The CLASS survey is scored according to three categories of answer: favorable, unfavorable, and neutral. Student responses to individual items are coded as +1 (agrees

with expert), -1 (disagrees with expert), and 0 (neutral) and responses in each group are added to give the score in each category (Adams, et. al., 2006). CLASS scores for each

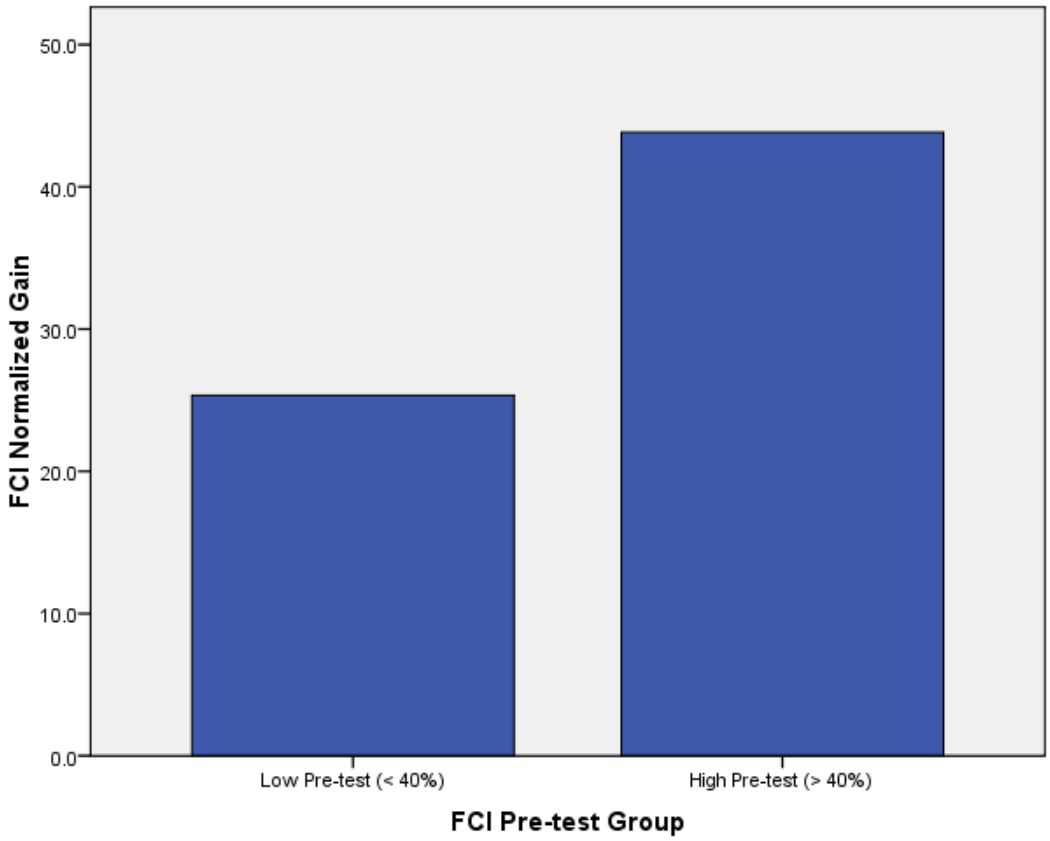


Figure 1

Student FCI Normalized Gains Organized by FCI Pre-Test Score

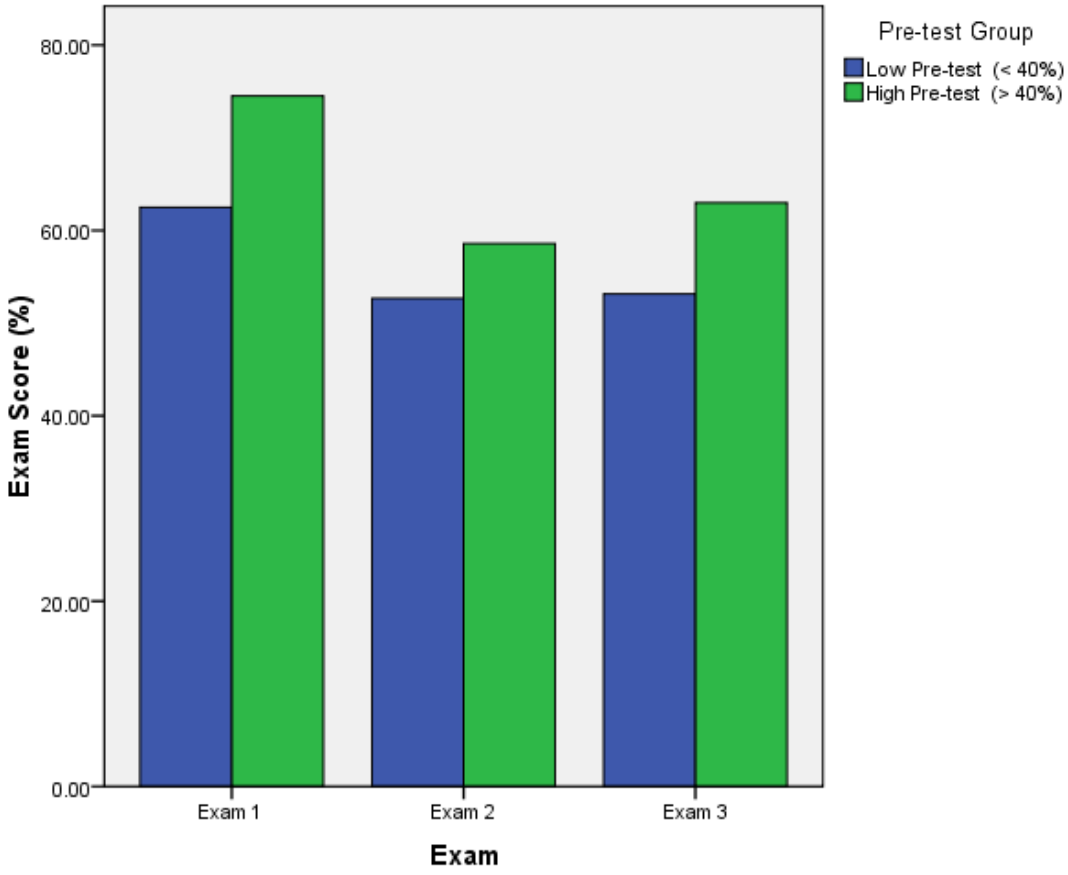


Figure 2

Student Exam Scores, Organized by FCI Pre-test Score

student were transformed to given an overall score and to allow correlations with other data. The transformation used a coding scheme that assigned a score of 2 to responses that agree with experts, 1 to neutral responses, and 0 to responses that disagree with experts. This gives a total possible score of 76, which would occur if a student agreed with the expert response on every scored question. A score of 50 or above is then given a rating of overall favorable, between 24-49 is overall neutral, and below 24 is overall unfavorable. In addition, the CLASS questions that correspond to the views categories were scored separately, using the same scheme. No significant correlations were found between demographic categories and CLASS pre- or post-test data. Therefore, all analysis is performed with the entire set of participants, n=93, unless otherwise stated. Tables 14 through 17 summarize the CLASS data for the participants.

Table 14

CLASS Average Scores, Scaled, Both Overall and in Views Categories

CLASS Category	M	SD	Range
Overall (max. score = 76)			
Pre-test	47.4	9.5	21 to 66
Post-test	46.9	11.7	22 to 71
Value (max. score = 12)			
Pre-test	6.86	3.06	0 to 12
Post-test	6.27	3.31	0 to 12
Effort (max. score = 14)			
Pre-test	10.44	2.47	2 to 14
Post-test	10.27	2.84	4 to 14
Confidence (max. score = 8)			
Pre-test	6.13	1.85	0 to 8
Post-test	5.27	2.28	0 to 8
Connectedness (max. score = 18)			
Pre-test	10.11	3.29	2 to 17
Post-test	9.87	3.85	2 to 18
Applicability (max. score = 8)			
Pre-test	5.43	2.31	0 to 8
Post-test	5.33	2.48	0 to 8

Note. n=93

Transformed CLASS scores overall and in every category declined slightly, indicating that students' views of physics were less favorable after instruction than before. Paired t-tests were run for pre- and post-test scores for the CLASS survey overall and in each of the views categories. The slight difference between pre- and post-test scores overall was significant ($p<0.001$), as well as in the category of confidence ($p=0.001$), but the differences were not statistically significant for any of the other views categories for the scaled CLASS scores.

However, when scores are looked at in terms of favorable, neutral, and unfavorable scores, it shows that overall, it can be seen that the increase in unfavorable scores is generally due to a decrease in neutral scores from pre- to post-tests, while the favorable scores remained the same overall or declined only very slightly in most views categories. This trend was also seen in the views category of effort, which deals with students' willingness to put effort into studying and learning physics. The average favorable score increased in the views category of applicability, which investigates students' views on the applicability of physics concepts to explain topics in other subjects and everyday phenomena. However, the unfavorable score in this category also increased, while the neutral score decreased. Favorable scores in the categories of value, confidence, and connectedness decreased over the course of the semester. In the value and confidence categories, the unfavorable score also increased, while the neutral score in the value category decreased. In the confidence category, investigating students' confidence in their ability to learn or do physics, the neutral score increased, indicating that not all the loss in favorable scores contributed to the post-test unfavorable score. In the connectedness category, investigating students' views of the interconnectedness of

various topics in physics, the unfavorable score remained essentially unchanged, while the neutral score increased. This indicates that the loss in favorable views of physics in this category did not necessarily contribute to an increase in unfavorable views. Of all these changes in favorable views, the only significant differences between pre- and post-test scores occur for the categories of confidence favorable and unfavorable.

Table 15

CLASS Average Favorable Scores, Overall and in Views Categories

CLASS Category	M	SD	Range
Overall (max. score = 38)			
Pre-test	19.37	6.03	28
Post-test	19.37	6.89	31
Value (max. score = 6)			
Pre-test	2.61	1.76	6
Post-test	2.37	1.76	6
Effort (max. score = 7)			
Pre-test	4.43	1.67	7
Post-test	4.44	1.77	7
Confidence (max. score = 4)*			
Pre-test	2.59	1.20	4
Post-test	2.10	1.42	4
Connectedness (max. score = 9)			
Pre-test	4.10	1.97	8
Post-test	3.88	2.26	9
Applicability (max. score = 4)			
Pre-test	2.16	1.39	4
Post-test	2.22	1.46	4

Note. n=93

* $p<0.01$

Table 16

CLASS Average Neutral Scores, Overall and in Views Categories

CLASS Category	M	SD	Range
Overall (max. score = 38)			
Pre-test	8.69	4.55	24
Post-test	8.19	4.34	22
Value (max. score = 6)			
Pre-test	1.63	1.23	4

Post-test	1.54	1.39	6
Effort (max. score = 7)			
Pre-test	1.58	1.42	4
Post-test	1.54	1.39	6
Confidence (max. score = 4)			
Pre-test	0.95	0.97	4
Post-test	1.08	1.02	4
Connectedness (max. score = 9)			
Pre-test	1.91	1.44	7
Post-test	2.11	1.46	6
Applicability (max. score = 4)			
Pre-test	1.11	1.01	3
Post-test	0.90	1.10	4

Note. n=93

Table 17

CLASS Average Unfavorable Scores, Overall and in Views Categories

CLASS Category	M	SD	Range
Overall (max. score = 38)			
Pre-test	9.95	4.38	20
Post-test	10.44	5.49	25
Value (max. score = 6)			
Pre-test	1.75	1.53	6
Post-test	2.10	1.84	6
Effort (max. score = 7)			
Pre-test	0.99	1.13	5
Post-test	1.17	1.31	5
Confidence (max. score = 4)*			
Pre-test	0.46	0.87	4
Post-test	0.83	1.06	4
Connectedness (max. score = 9)			
Pre-test	2.99	1.60	7
Post-test	3.01	1.84	7
Applicability (max. score = 4)			
Pre-test	0.73	1.12	4
Post-test	0.88	1.25	4

Note. n=93

*$p<0.01$

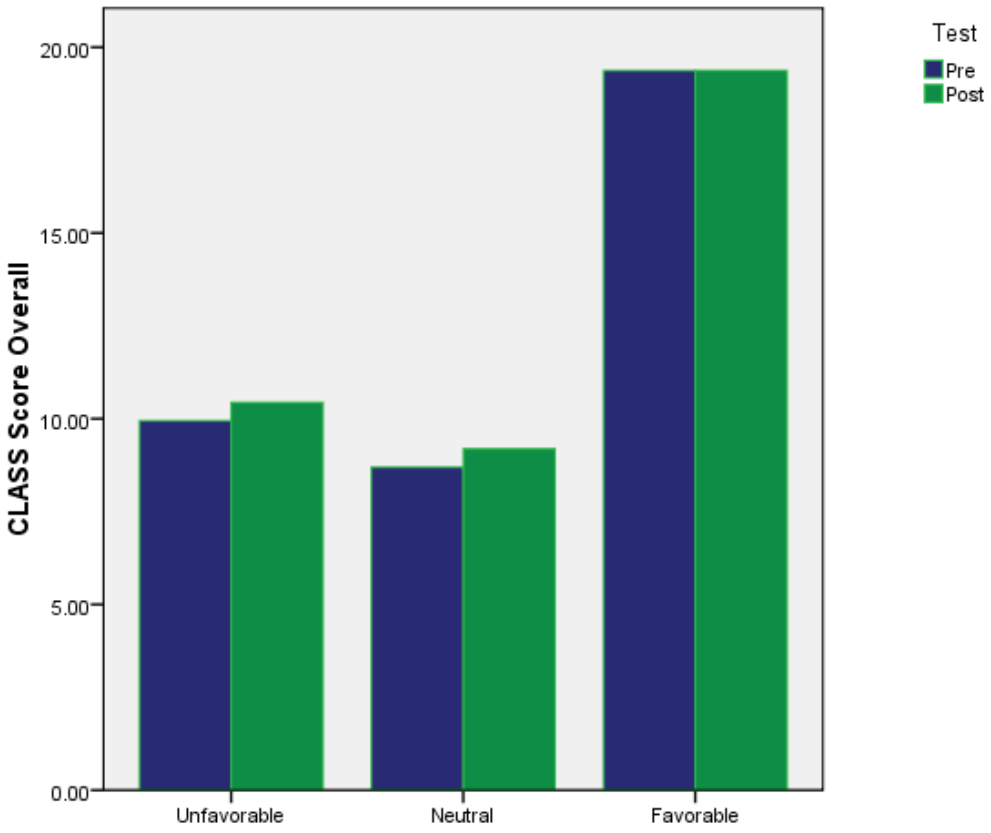


Figure 3

CLASS Mean Overall Scores (maximum 38)

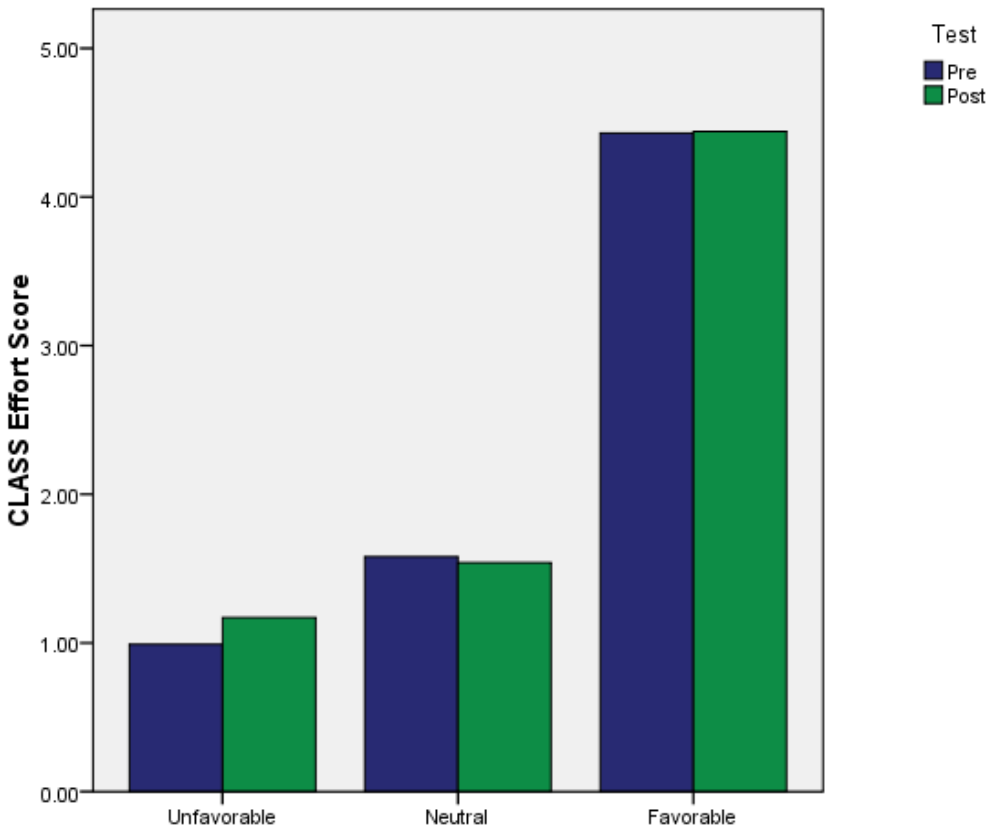


Figure 4

CLASS Mean Scores in the Category of Effort (maximum 7)

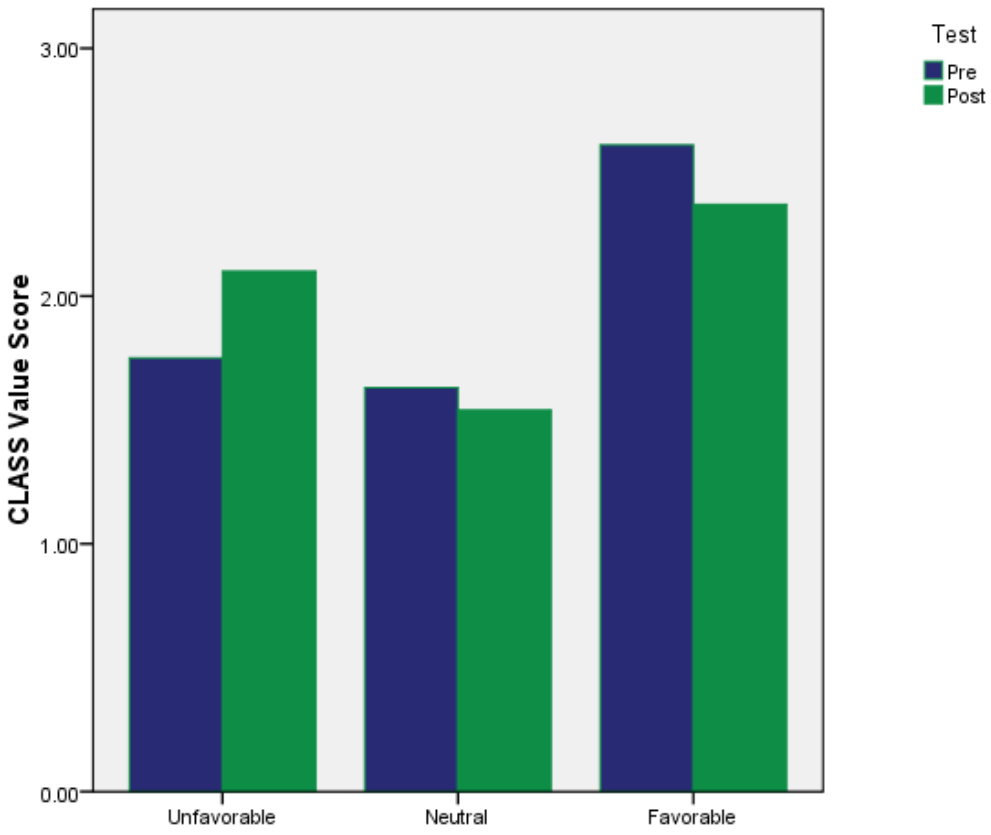


Figure 5

CLASS Mean Score in the Category of Value (maximum 6)

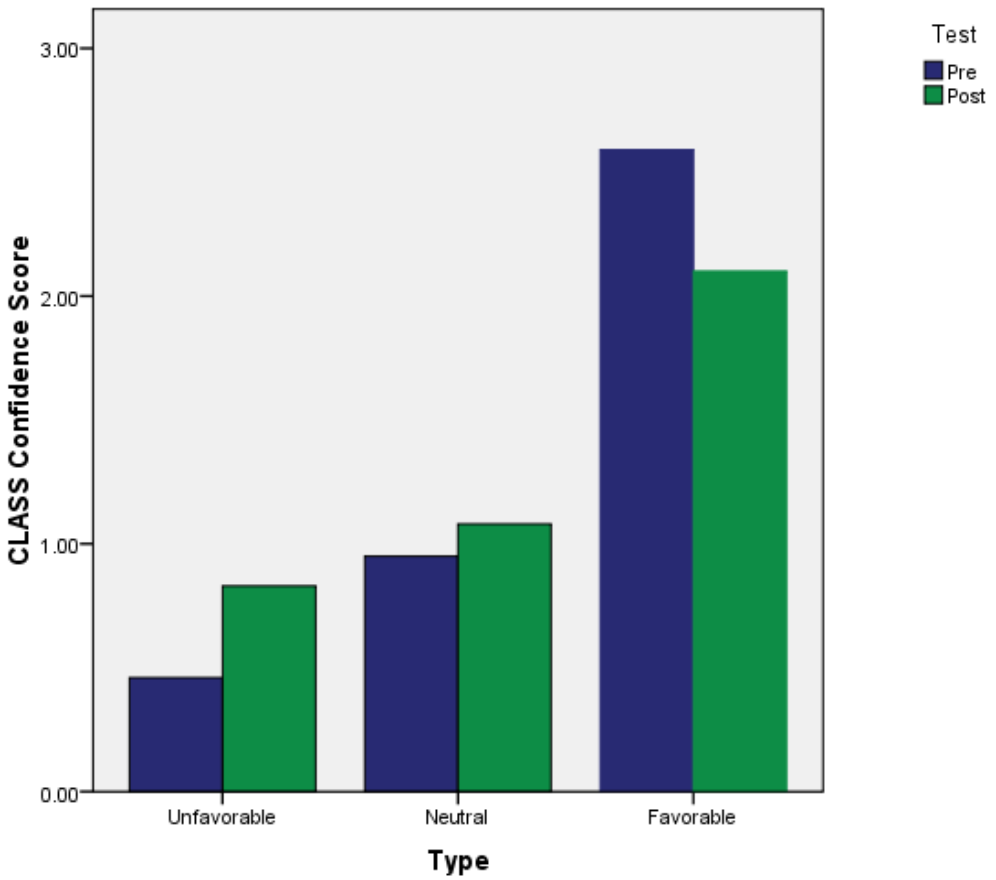


Figure 6

CLASS Mean Score in the Category of Confidence (maximum 4)

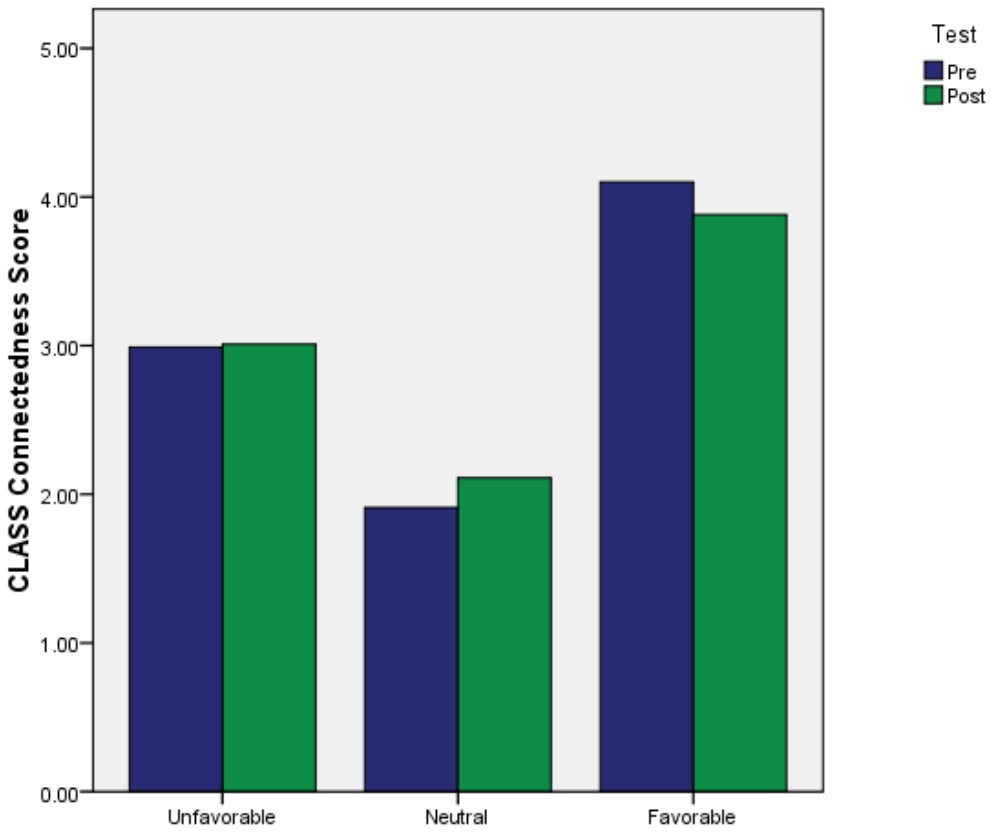


Figure 7

CLASS Mean Score in the Category of Connectedness (maximum 9)

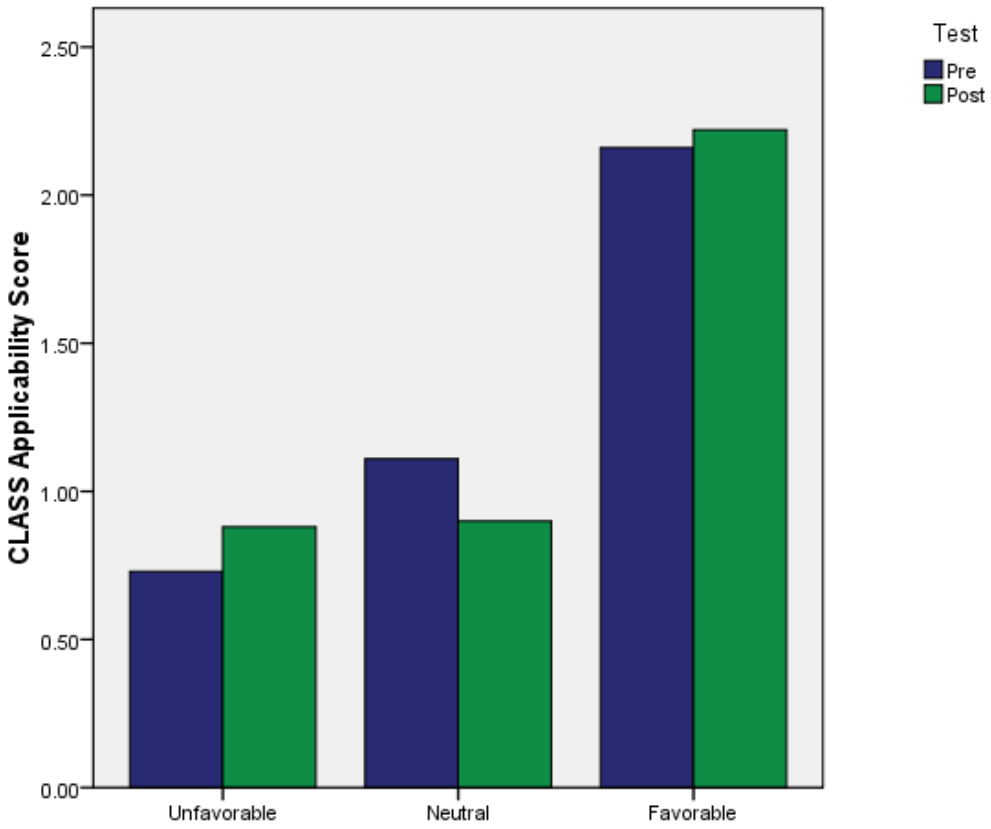


Figure 8

CLASS Mean Score in the Category of Applicability (maximum 4)

Students were chosen to participate in interviews based on their CLASS pre-test scores and were sorted into groups with high, medium, and low CLASS pre-test scores. Ten students completed the series of three interviews throughout the semester, with two in the high scoring, or overall favorable, group, five in the medium scoring, or overall neutral, group, and three in the low scoring, or overall unfavorable, group. Approximately half of the interview questions probed student views of physics and these interview questions were based in part on CLASS items, in order to more deeply probe student views of physics. Table 18 summarizes CLASS and interview overall scores for students in the pre-test high scoring group. Tables 19 and 20 do the same for the pre-test medium and low scoring groups.

Table 18

CLASS Scores and Interview Scores, Overall and in Views Categories, for the CLASS Pre-test High Scoring Group

		Item				
		CLASS				
Views Category	Score	Pre	Post	Interview 1	Interview 2	Interview 3
Overall	M	65.0	68.0	17.5	17.5	18.5
	SD	1.41	4.24	2.12	3.53	2.12
	Range	64-66	65-71	16-19	15-20	17-20
Value	M	10.5	11.5	6.0	5.5	5.5
	SD	2.12	0.71	0.0	0.71	0.71
	Range	9-12	11-12	6-6	5-6	5-6
Effort	M	13.5	13.5	4.0	4.5	5.0
	SD	0.71	0.71	1.41	2.12	1.41
	Range	13-14	13-14	3-5	3-6	4-6
Confidence	M	7.5	8.0	4.0	4.5	5.0
	SD	0.71	0.0	1.41	2.12	1.41
	Range	7-8	8-8	3-5	3-6	4-6

Connectedness	M	14.5	15.0	4.0	4.0	4.0
	SD	0.71	1.41	0.0	0.0	0.0
	Range	14-15	14-16	4-4	4-4	4-4
Applicability	M	8.0	8.0	1.5	3.5	4.0
	SD	0.0	0.0	0.71	0.71	0.0
	Range	8-8	8-8	1-2	3-4	4-4

Note. n=2

Note. The maximum scores for the CLASS tests are as follows: overall (max. score = 76), value (max. score = 12), effort (max. score = 14), confidence (max. score = 8), connectedness (max. score = 18), and applicability (max. score = 8). The maximum scores for the interviews are as follows: overall (max. score = 20), value (max. score = 6), effort (max. score = 6), confidence (max. score = 6), connectedness (max. score = 4), applicability (max. score = 4).

Table 19

CLASS Scores and Interview Scores, Overall and in Views Categories, for the CLASS Pre-test Medium Scoring Group

		Item				
		CLASS				
Views Category	Score	Pre	Post	Interview 1	Interview 2	Interview 3
Overall	M	48.6	44.0	11.6	10.5	11.6
	SD	2.30	7.07	2.4	1.8	3.6
	Range	46-52	35-53	9-15	8-13	6-16
Value	M	8.0	6.0	3.2	2.4	2.8
	SD	2.74	2.24	1.48	1.34	2.17
	Range	4-11	3-9	1-5	1-4	0-6
Effort	M	10.4	10.4	2.8	1.8	3.0
	SD	1.82	2.19	1.1	1.3	1.23
	Range	8-13	8-14	2-4	0-3	1-4
Confidence	M	5.8	4.8	2.6	2.0	3.2
	SD	0.84	1.92	0.89	0.71	0.84
	Range	5-7	3-8	2-4	1-3	2-4
Connectedness	M	9.6	8.4	2.6	3.2	3.0
	SD	2.07	2.88	0.89	1.3	0.71
	Range	8-13	4-12	2-4	1-4	2-4

Applicability	M	6.8	5.8	1.8	1.8	1.4
	SD	0.45	1.48	0.84	0.84	1.14
	Range	6-7	4-8	1-3	1-3	0-3

Note. n=5

Note. The maximum scores for the CLASS tests are as follows: overall (max. score = 76), value (max. score = 12), effort (max. score = 14), confidence (max. score = 8), connectedness (max. score = 18), and applicability (max. score = 8). The maximum scores for the interviews are as follows: overall (max. score = 20), value (max. score = 6), effort (max. score = 6), confidence (max. score = 6), connectedness (max. score = 4), applicability (max. score = 4).

Table 20

CLASS Scores and Interview Scores, Overall and in Views Categories, for the CLASS Pre-test Low Scoring Group

		Item				
		CLASS				
Views Category	Score	Pre	Post	Interview 1	Interview 2	Interview 3
Overall	M	25.3	52.0	10.7	11.7	12.3
	SD	3.79	19.98	2.08	4.51	3.05
	Range	21-28	30-69	9-13	7-16	9-15
Value	M	2.0	6.0	1.67	3.00	3.00
	SD	2.0	4.58	0.58	2.0	1.73
	Range	0-4	1-10	1-2	1-5	2-5
Effort	M	6.33	11.0	4.0	4.0	3.0
	SD	0.57	2.0	1.0	1.73	0.0
	Range	6-7	-13	3-5	2-5	3-3
Confidence	M	1.0	5.67	3.33	3.33	3.33
	SD	1.73	2.31	1.53	2.08	0.58
	Range	0-3	3-7	2-5	1-5	3-4
Connectedness	M	5.0	11.67	3.33	2.33	3.33
	SD	1.73	5.51	0.58	0.58	1.16
	Range	4-7	6-17	3-4	2-3	2-4
Applicability	M	2.33	5.67	0.67	2.0	1.67
	SD	2.31	3.22	0.58	0.0	0.57
	Range	1-5	2-8	0-1	2-2	1-2

Note. n=3
Note. The maximum scores for the CLASS tests are as follows: overall (max. score = 76), value (max. score = 12), effort (max. score = 14), confidence (max. score = 8), connectedness (max. score = 18), and applicability (max. score = 8). The maximum scores for the interviews are as follows: overall (max. score = 20), value (max. score = 6), effort (max. score = 6), confidence (max. score = 6), connectedness (max. score = 4), applicability (max. score = 4).

The general trend through the semester was that student CLASS scores and interview scores in the initially favorable pre-test group were consistently high and increased or remained the same on interview questions in each of the views categories throughout the semester. The only exception to this trend for the high scoring pre-test group is in the views category of value, where student interview scores in this group declined slightly over the course of the semester. Students in the low pre-test group increased their CLASS scores overall and in every category and their interview scores increased or remained the same in every category but effort, where the scores decreased slightly. Students in the medium pre-test group decreased or remained the same in every category on the CLASS, while their interview scores increased slightly in the views categories of effort, confidence, and connectedness and decreased slightly or remained the same overall and in the views categories of value and applicability.

CLASS scores were tested for correlations against the interview scores overall and in the views categories and some correlations were found. This data is summarized in Table 21.

Table 21

CLASS Pre- and Post-test Scores Correlated to Student Interviews

	CLASS	
	Pre	Post
Views Category	R-value	R-value

Overall		
	0.64*	0.681*
Interview 1	0.435	0.895*
Interview 2	0.441	0.887*
Interview 3		
Value		
	0.597	0.565
Interview 1	0.283	0.817*
Interview 2	0.469	0.828*
Interview 3		
Effort		
	0.089	0.625
Interview 1	-0.02	0.576
Interview 2	0.437	0.335
Interview 3		
Confidence		
	-0.187	0.277
Interview 1	0.064	0.528
Interview 2	0.285	0.676*
Interview 3		
Connectedness		
	0.007	0.308
Interview 1	0.624	0.293
Interview 2	0.259	0.824*
Interview 3		
Applicability		
	0.562	0.315
Interview 1	0.258	0.416
Interview 2	0.381	0.810
Interview 3		

Note. n=10

* $p < 0.05$

The overall interview scores are significantly correlated to the CLASS overall post-test score in all cases and to the CLASS overall pre-test only in the case of interview 1. However, there are fewer significant correlations between interview scores and CLASS scores in the views categories, with significant correlations occurring only for interviews 2 and 3 and the CLASS post-test in the value category, and only with interview 3 and the CLASS post-test in the confidence and connectedness categories.

That only the CLASS post-test scores are significantly correlated with interview scores in any categories is not surprising, as interviews all occurred after some instruction, when students have had more exposure to the subject and the teaching methods.

Correlations Between Student Content Knowledge and Views of Physics. Results of the tests of student knowledge were tested against student views of physics for all participants to check for any interesting correlations. There were some significant correlations between FCI scores and normalized gains and CLASS scores. These correlations are summarized in Table 22.

Table 22

CLASS Pre- and Post-test Scores Correlated to FCI Pre- and Post-test Scores and Normalized Gains for All Participants

	CLASS	
FCI	Pre	Post
Pre	.192	.086
Post	.356*	.340*
Norm. Gains	.358*	.387*

Note. n=93

* $p < 0.05$

Students who completed the surveys were sorted into CLASS pre-test groups, in a manner similar to that used to choose students to participate in interviews. Of the students who completed the survey, none had overall unfavorable CLASS pre-test scores, 32 had overall neutral CLASS pre-test scores, and 19 had overall favorable CLASS pre-test scores. Survey and interview participants were then combined to make a group of 61 participants and correlations and descriptive statistics were run to see if any interesting patterns arose. There were no correlations between student scores on tests of content knowledge or student views with this subset of participants. As with the larger group,

there were some significant correlations between FCI scores and normalized gains and CLASS scores. These correlations are summarized in Table 23.

Table 23

CLASS Pre- and Post-test Scores Correlated to FCI Pre- and Post-test Scores and Normalized Gains for Interview and Survey Participants

	CLASS	
FCI	Pre	Post
Pre	.120	.035
Post	.351*	.332*
Norm. Gains	.387*	.423*

Note. n=61

* $p < 0$.

When the FCI pre- and post-test scores and normalized gains for this group are separated according to CLASS pre-test group, an interesting pattern emerges. This data is summarized in Table 24.

Table 24

FCI Pre- and Post-test Scores and Normalized Gains, Organized by CLASS Pre-test Group for Interview and Survey Participants

CLASS Pre-	FCI Pre			FCI Post			Normalized Gain		
Test Group	M(%)	SD	Range	M(%)	SD	Range	M(%)	SD	Range
Favorable	31.5	14.1	50	66.7	18.3	56.7	53.4	20.2	57.8
Neutral	28.6	11.8	40	44.4	14.3	60	21.7	18.7	71.8
Unfavorable	35.6	5.1	10	62.2	15.7	30	42.0	23.0	45.6

Note. n=61

Students in all the CLASS pre-test groups had similar FCI pre- test scores, with the students in the initially unfavorable group scoring slightly higher on the pre-test than students in either the initially favorable or neutral groups. Students in the initially favorable group had the highest gains, followed by students in the initially unfavorable group, and finally by students in the initially neutral group. The initially neutral group

had approximately half the normalized gains of students in the initially unfavorable group and less than half the normalized gains of students in the initially favorable group.

Instructional Strategies to Support Student Learning and Features of Course Design

In order to test which of the instructional strategies was most helpful to student learning of physics, student responses to interview and survey questions about the instructional strategies and class activities were tabulated. Student responses were tabulated individually for each instructional strategy and class activity for each survey or interview according to the number of times they mentioned an instructional strategy or class activity as being helpful or making learning harder. In addition, students were given an overall score for each survey or interview and an overall score for all the surveys or interviews for the semester based on the same criteria. All of these scores were tested against student FCI scores and gains and CLASS scores. No correlations were found between the students' scores for the individual class activities and instructional strategies and either FCI scores or CLASS scores. There were also no correlations between any of the overall scores and CLASS scores. However, all of the overall scores, for each survey or interview individually and for the entire semester, were significantly correlated with FCI post-test scores and normalized gains. This shows that, while it is not possible with this study to separate out which of the instructional or class activities contributes the most to student learning, the interaction of all the activities and strategies together does seem to contribute to student learning. The results of this analysis are reported in Table 25

Table 25

Student Responses to Whether Instructional Strategies and Class Activities are Helpful Correlated to FCI Post-test Scores and Normalized Gains.

	Test	
Survey/Interview	FCI Pre-test Score	FCI Normalized Gain <g>
One	0.392	0.352
Two	0.363	0.285*
Three	0.386	0.369
Overall Score	0.464	0.469

Note: n=61

Note: All are significant at the $p<0.05$ level

*Not significant, $p = 0.208$

In addition to the interview questions about students' views of physics, students participating in interviews were also asked questions about which of the instructional strategies and in-class activities they found most and least helpful to learning physics, as well as which aspects, if any, they would change, and which aspects led to an increased appreciation of physics as a subject. These interview responses were transcribed and tabulated according to the frequency of responses pertaining to particular aspects of the instructional strategies and in-class activities. Tables 26 through 29 summarize these results.

Table 26

Student Responses to Interview Question One[a] About Which Instructional Strategies and Class Activities Were Most Helpful

Instructional Strategies and Class Activity	Number of Responses		
	Interview 1	Interview 2	Interview 3

Class Activities			
Generally Helpful	8	3	7
	0	3	2
Clickers	5	1	3
Demonstrations	2	2	0
Tutorials			
Other			
Not Helpful			
	0	1	0
Share Ideas			
	4	5	6
Generally	3	4	3
Helpful	0	0	2
Clickers	3	0	0
Demonstrations	0	0	0
Tutorials			
Other			
Not Helpful			
	0	1	0
Explain Reasoning			
	7	5	7
Generally	1	1	1
Helpful	0	0	0
Clickers	1	2	0
Demonstrations	1	1	0
Tutorials			
Other			
Not Helpful			
	0	1	2
Revise Ideas			
	5	3	7
Generally	2	3	1
Helpful	0	0	0
Clickers	0	1	0
Demonstrations	2	0	0
Tutorials			
Other			
Not Helpful	0	0	0

Note. n=10

Note. Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were asked separately about each of the instructional strategies.

[a] Which aspects of the in-class activities were most helpful to learning physics, in general or in terms of sharing ideas with other students, explaining your reasoning either verbally or in writing, and revising or re-thinking your ideas?

Interview participants found certain class activities, such as clickers and, to a lesser extent, tutorials, to be helpful independent of the instructional strategies. In addition, students tended to find the instructional strategies of sharing ideas, explaining their reasoning, and revising ideas to be generally helpful in themselves, but particularly in the context of clicker questions. This trend remained relatively steady throughout the semester, although more students found tutorials to be helpful to their learning at the beginning than at the end.

Table 27

Student Responses to Interview Question Two[a] About Which Instructional Strategies and Class Activities Made Learning Harder

Instructional Strategies and Class Activity	Number of Responses		
	Interview 1	Interview 2	Interview 3
Class Activities			
Generally Harder	1	1	0
	0	0	0
Clickers	5	8	6
Demonstrations	0	0	0
Tutorials	2	0	3
Other			
Not Harder			
Share Ideas			
	5	3	2
Generally Harder	0	0	2
Clickers	0	0	0
Demonstrations	2	1	3
Tutorials	0	0	0
Other	3	6	4
Not Harder			
Explain Reasoning			
	3	1	3
Generally Harder	0	0	1
Clickers	0	0	0
Demonstrations	2	1	0
Tutorials	0	0	0
Other			
Not Harder	0	4	6

Revise Ideas			
	2	0	5
Generally Harder	0	0	1
Clickers	0	0	0
Demonstrations	1	0	0
Tutorials	0	0	0
Other			
Not Harder	3	6	2

Note. n=10

Note. Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were asked separately about each of the instructional strategies.

[a] Were there any aspects of the in-class activities that made learning physics harder, in general or in terms of sharing ideas with other students, explaining your reasoning either verbally or in writing, and revising or re-thinking your ideas?

The aspect of the course that interview participants commonly felt made it more difficult to learn physics was the tutorials. Students found these to be difficult in themselves and also in the context of each of the instructional strategies. One student commented about the difficulties found when working together on tutorials, "It's just confusing when everybody has different answers and you don't know which one is right and then you start questioning yours. I did that a lot and my answer ended up being the right one and I shouldn't have switched." This student found that working in groups on tutorials and convincing other students, and being convinced by them, to be confusing. However, although many students cited tutorials in general, and sharing ideas and explaining their reasoning on tutorials specifically, to make learning more difficult, many students in all interviews did not find that any aspects of the course made it more difficult for them to learn physics.

Table 28

Student Responses to Interview Question Three[a] *About Which Instructional Strategies or Class Activities They Would Change*

Instructional Strategies and Class Activities	Number of Responses		
	Interview 1	Interview 2	Interview 3
Sharing Ideas	0	1	1
Explaining Reasoning	0	0	0
Revising Ideas	0	0	0
Clickers	0	1	0
Demonstrations	0	1	0
Tutorials	6	7	7
Other	0	1	1
Nothing	4	0	1

Note. n=10

Note. Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were not asked separately about the instructional strategies in this question.

[a] Is there anything about the in-class activities that you would change?

Students most commonly said they would change some aspect of the tutorials., although none of the students in the initially favorable group indicated this on any of the interviews. Specifically, many students in the initially neutral and unfavorable groups, in all three interviews, commented that they would prefer that the instructor "teach" the tutorials or give tutorial solutions instead of or before expecting students to work through the questions themselves. A typical response from the initially neutral pre-test group, on interview 2, was as follows, "Yes, change the tutorials. I think that maybe going through them question by question would make them easier. Going through them question by question, in front of the entire class, or maybe teaching the information on them in depth and then going over the tutorials … would make it better." One student in the initially high scoring pre-test group found that sharing ideas, particularly in the context of clicker questions, made it more difficult to learn physics. Specifically, this student felt that

having to explain answers and solutions to students who had not done the reading for class that day or who were sincerely confident in a wrong answer was frustrating and not helpful.

Table 29

Student Responses to Interview Question Four[a] *About Which Instructional Strategies or Class Activities Increased Their Enjoyment of Physics*

Instructional Strategies and Class Activities	Number of Responses		
	Interview 1	Interview 2	Interview 3
In General			
	1	2	7
Clickers	7	5	2
Demonstrations	3	2	3
Tutorials	0	1	0
Other	0	2	0
Nothing/No Enjoyment			
Share Ideas			
	9	5	6
Generally Better	0	0	3
Clickers	0	0	0
Demonstrations	1	0	2
Tutorials	0	0	0
Other	1	1	0
Nothing/No Enjoyment			
Revise Ideas			
	5	2	7
Generally Better	1	0	1
Clickers	0	0	0
Demonstrations	0	0	0
Tutorials	0	0	0
Other	0	0	0
Nothing/No Enjoyment			

Note. n=10

Note. Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were asked separately about each of the instructional strategies.

[a] Were there any aspects of the in-class activities that increased your enjoyment of physics or your feelings about its usefulness, in general or in terms of sharing ideas with other students and revising or re-thinking your ideas?

Interview participants were also asked if there were any aspects of the course or in-class activities that they enjoyed or that contributed to seeing physics as applicable to everyday life. Many students pointed to in-class demonstrations as helping them to enjoy the class and helping them to see the applicability of physics concepts. Students also had similar comments about the use of clickers and even tutorials helping them to see the usefulness of physics in the world. In addition, when asked specifically about the instructional strategies of sharing and revising their ideas, most students in all interviews said that these contributed to increasing their overall favorable view of physics as well as their opinions about its usefulness.

Students who did not participate in interviews were invited to complete open-ended surveys based on these interview questions. Fifty-one participants completed all three surveys, both pre- and post-tests, and the demographic survey. These open-ended surveys took place three times throughout the semester, during the same weeks as the interviews and contained similar questions to those on the interviews about the instructional strategies. However, the survey questions did not explicitly ask students about the instructional strategies separately from the class activities and students were free to give more than one answer to any question, skip questions, or elaborate on any answers given. Tables 30 through 33 give a cross-tabulation of the answers given to each of the survey questions.

Table 30

Cross-tabulation of Student Responses to Survey Question One[a] *About Which Instructional Strategies and Class Activities were Helpful*

	Survey 1			Survey 2			Survey 3		
Activities Identified as Helpful	Generally Helpful	Share Ideas	Justify Reasoning	Generally Helpful	Share Ideas	Justify Reasoning	Generally Helpful	Share Ideas	Justify Reasoning
All Activities Generally		13	3	1	12	3		5	8
Clickers only		10		1	9	1	5	12	2
Demonstrations only	1			1	2		1		2
Tutorials only	1	5	1	2	3		2	2	1
Clickers and Demos	3	2		2	2		5	2	
Tutorials	2	7		3	3			2	
Demonstrations and Tutorials	1				1				

Note: n=51

Note: Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were not asked separately about each of the instructional strategies

Note: In surveys 1 and 2, two students replied that none of the class activities or instructional strategies were helpful to their learning. No students responded this way in survey 3.

[a] Are there any aspects of the in-class activities that you found helpful to learning or understanding physics concepts.

Across all three surveys, participants were more likely to cite sharing ideas, either alone or in combination with some in-class activities, to be the most helpful aspect of the class in their learning of physics. One student wrote, "I like working in groups because it helps me see it from someone else's perspective and helps me think about concepts differently." This was typical of comments from students who found working together and sharing ideas to be helpful. The activity most commonly found to be helpful was the use of clicker questions during the lecture. Many students felt that the clicker questions were a good review and helped them to think about new concepts in a useful way. Although the clicker questions were the most popular activity in terms of helpfulness and promoting learning, many students also felt that working together and sharing ideas in the context of doing tutorials was also helpful.

Table 31

Cross-tabulation of Student Responses to Survey Question Two[a] *About Which Instructional Strategies and Class Activities Made Learning Harder*

	Survey 1			Survey 2			Survey 3		
Activities Identified as Making Learning Harder	Generally Harder	Share Ideas	Justify Reasoning	Generally Harder	Share Ideas	Justify Reasoning	Generally Harder	Share Ideas	Justify Reasoning
All Activities Generally		2	8	1	12	3		5	8
Clickers only	3		3	1	9	1	5	12	2
Demonstrations only				1	2		1		2
Tutorials only	1	5	1	2	3		2	2	1
Clickers and Demos	3	2		2	2		5	2	
Clickers and Tutorials	2	7		3	3			2	
Demonstrations and Tutorials	1				1				

Note: n=51

Note: Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were not asked separately about each of the instructional strategies.

Note: In survey 1, six students replied that none of the activities or instructional strategies made learning harder. In survey 2, four students replied that none of the activities or instructional strategies made learning harder. In survey 3, five students replied that none of the activities or instructional strategies made learning harder.

[a] Are there any aspects of the in-class activities that you felt made it harder to learn or understand physics concepts?

When asked what aspects of the class made learning more difficult, the majority of students cited tutorials, either alone or along with some other activity. This result is similar to the interview results, where students also said that tutorials were the most confusing activity and made learning physics more difficult. Students said that tutorials were repetitive and confusing, particularly when used to introduce a concept. One student said,

> Some of the tutorials confuse me. I feel like I don't understand some of the questions and don't know if I'm even on the right track. I also wish that they didn't ask what feels like the same question multiple times. It makes me unsure of an answer that may be right and then I can convince myself I must be wrong.

Although they do not explicitly say so, this comment also indicates that this student also found that revising their ideas was sometimes confusing. It was a common theme throughout the surveys that students, although they did not necessarily say so explicitly, felt uncomfortable being asked to discuss concepts and revise their thinking before they were given definitively correct answers.

Table 32

Cross-tabulation of Student Responses to Survey Question Three[a] *About Which Instructional Strategies and Class Activities They Would Change*

	Survey 1			Survey 2			Survey 3		
Activities Identified as Something Students Would Change	All Activities Generally	… and Tutorials	… and Other	All Activities Generally	… and Tutorials	… and Other	All Activities Generally	… and Tutorials	… and Other
All Activities Generally	1			1					
Clickers	1	2		1	4	1	5	2	
Demonstrations	1	1	1	2	1	1			
Tutorials	28		2	21		3	27		1
Other	4			6			9		
Work together/Share ideas	1			1	2			1	

Note: n=51

Note: Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were not asked separately about each of the instructional strategies.

Note: In survey 1, nine students replied that they would not change anything about the course. In survey 2, seven students replied that they would not change anything about the course. In survey 3, six students replied that they would not change anything about the course.

[a] Are there any aspects of the in-class activities that you would change?

When asked what aspects of the in-class activities they would change, again, students overwhelmingly chose some aspect of the tutorials. As with the interviews, the most common suggestion was to "teach" the tutorials before giving them to students to complete. Other suggestions included giving more quantitative practice problems in class and lecturing more instead of making students work together on clicker questions and tutorials.

Table 33

Cross-tabulation of Student Responses to Survey Question Four[a] *About Which Instructional Strategies and Class Activities Made Physics More Enjoyable*

	Survey 1		Survey 2		Survey 3	
Activities Identified as Most Enjoyable	Generally Enjoyable	Share Ideas	Generally Enjoyable	Share Ideas	Generally Enjoyable	Share Ideas
All Activities Generally	1	7	7	1	3	2
Clickers only		2			3	1
Demonstrations only	1	12	23	2	23	1
Tutorials only	2	2	4		1	
Clickers and Demonstrations	4	1	3		3	
Tutorials	3		1		2	
Demonstrations and Tutorials			1			

Note: n=51

Note: Some participants did not answer every part of every question and some participants gave multiple responses to some questions. Participants were not asked separately about each of the instructional strategies.

Note: In survey 1, eleven students replied that none of the activities made learning physics more enjoyable. In survey 2, seven students replied that none of the activities made learning physics more enjoyable. In survey 3, four students replied that none of the activities made learning physics more enjoyable.

When asked if any aspect of the in-class activities increased their enjoyment of physics or their feelings about its usefulness, most students in on every survey said that they most enjoyed the demonstrations. They also overwhelmingly said that seeing demonstrations performed helped them to make connections between physics concepts and real world phenomena. A large minority of the students in each survey also felt that doing tutorials in class helped them to see the usefulness of physics, even though many of those same students had previously in the same survey had cited tutorials as making it harder to learn physics and as the main thing about the in-class activities they would change.

One notable theme from both the interviews and open-ended surveys was that students tended to view the instructional strategies of sharing ideas, explaining their reasoning, and revising ideas to be separate class activities in themselves, instead of as overarching themes that were important aspects of all of the classroom activities. Students also separated different components of activities into separate activities. For instance, students viewed demonstrations as consisting of only the physical demonstration that they could view, and any participation aspects of the demonstration activity, including answering clicker questions and discussion predictions, were considered to be completely separate. However, students in both the interview and survey groups did feel that seeing demonstrations helped them to make connections between physics concepts and everyday phenomena.

Another theme throughout both the surveys and the interviews was that students were uncomfortable being asked to reason through questions and problems without being given a definitive answer to every single thing. This was mostly evident in complaints

about the use of tutorials making it more difficult for them to learn and when asked which activities they would change. Since tutorials are most often used to introduce a concept, students typically have very little, if any, prior knowledge on that topic before beginning the tutorial and most of the interview and survey participants seemed conflicted about their use. When asked about which aspects of the class made it harder to learn, one student said, "I felt the tutorials that covered information about concepts that we have not went over enough did not help me understand what was going on." This same student, when asked what could be changed, said they would "make the tutorials graded for completion and would also only give out the tutorials after the material is covered in lecture." Finally, when asked about what aspects of the class increased feelings of usefulness about physics said, "Most of the tutorials helped me to understand how some physics concepts worked, which increased my enjoyment in the class because I knew the material. The tutorials also helped me to see physics applied to everyday life, which also kept me interested in the class." This type of responses to the survey and interview questions was not at all unusual. Many students felt that the tutorials were difficult and they did not like them, but also that they felt like the tutorials were useful and helped them to see connections between various physics concepts.

Tutorials, longer worksheet-based activities that students work on in groups and that introduce a topic or concept, were part of the in-class activities approximately every second or third class meeting and collected at four points during the semester. Sixty-one students completed both the pre- and post-test FCI and CLASS and all four of the collected tutorials. The tutorials were coded according to the instructional strategies, particularly how well students justified their reasoning, integrated ideas, and applied their

reasoning. Tutorials were scored on either a two or three point scale, depending on which learning construct was being considered. Questions that required students to apply their reasoning were scored on a three-point scale, in a manner similar to that of the exam questions. Questions that required students to justify their reasoning were also scored on a three-point scale, while those that investigated whether students integrated ideas were scored on a two-point scale. Tutorials were based on topics that corresponded to exam questions, but there were no correlations found between student responses to tutorial questions and scores on exams or FCI scores. There were also no correlations found between tutorial responses and CLASS scores or with any of the demographic data. Tutorial averages according to learning construct and tutorial are listed in Table 34.

Table 34

Tutorial Scores, Organized by Topic and Instructional Strategy

Tutorial	M	SD	Range
T1: Kinematics			
Integrate Ideas	1.44	0.719	2
Apply Reasoning	1.70	0.937	3
T2: Forces			
Justify Reasoning	1.89	0.877	3
Apply Reasoning	2.20	0.726	3
T3: Newton's Laws			
Justify Reasoning	1.49	0.649	2
Integrate Ideas	1.34	0.680	2
T4: Momentum			
Integrate Ideas	1.90	0.300	1
Apply Reasoning	2.26	0.947	3

Note. n=93

Note. Maximum score for integrate ideas = 2; Maximum score for justify reasoning = 3; Maximum score for apply reasoning = 3.

It is notable that students scored higher on tutorial questions that required them to apply their reasoning to solve quantitative problems than when they were required to justify their reasoning in words on conceptual problems or when required to integrate two

or more ideas into a single concept. This indicates that students continued to struggle with these skills throughout the term.

Summary

The main findings in this study included findings about students' physics content knowledge, views of physics, and the instructional strategies.

- Physics Content Knowledge: The average normalized gain for the course was 0.32. This falls within the low portion of the medium gain range as reported by Hake (1998). When divided into groups according to FCI pre-test score, a significant difference was found in students normalized gains according to whether their pre-test scores were very low (<40%) or higher (>40%), with students in the high pre-test group having much higher normalized gains than students in the low pre-test group. This effect was also seen on class exams.
- Views of Physics: Student views of physics remained relatively unchanged from pre-test to post-test. There was no significant difference between student pre-test and post-test CLASS scores, except in the views category of confidence, where students' views declined slightly.
- Instructional Strategies to Support Student Learning: There was a positive correlation between student responses on interviews and surveys as to whether they found the instructional strategies helpful to learning physics and FCI pre-test scores and normalized gains. No correlations were found between student responses about any of the instructional strategies individually and FCI scores, however there was a significant correlation between students' responses about the instructional strategies all together and FCI scores and normalized gains.

Chapter Six

Discussion

This study examined student conceptual understanding of physics and student views of physics in a large enrollment college physics course without a separate small group recitation section. Specifically, this study examined whether the use of interactive engagement methods can lead to improved student conceptual understanding and more expert-like views of physics comparable to that reported in the literature for other interactive engagement courses is possible for a course with this organizational structure. In addition, this study investigated which features of interactive engagement activities making up the course design contributed to the most to improved conceptual understanding and more expert-like views of physics.

Some common features of the interactive engagement activities have been identified by this study that contribute to learning gains and more expert-like views of physics. These findings can be used to provide recommendations for future interactive engagement courses with a similar structure. In this chapter, I will discuss how the learning gains and student views of physics observed in this study fit in the context of other research on this topic. I will also discuss the various aspects of the interactive activities used and the instructional strategies that affected those gains. Finally, I will discuss some possible directions for future research.

Student Learning and Views About Physics.

Physics content knowledge. Student gains in physics content knowledge were measured using the Force Concept Inventory (FCI) as a pre- and post-instruction assessment, as well as three times during the semester using course exams. The average

normalized gain, <g>, between pre- and post-testing is considered to be the statistic of note in the physics education community for determining the overall effectiveness of instruction. The normalized gain is the proportion between the absolute gain and the possible gain for any student. Average normalized gain for a class is the average of the normalized gains for the class. The average normalized gain for this course was 0.32, which is in the low portion of the medium gain range for an interactive engagement course, as reported by Hake (1998), although no traditionally taught classes in Hake's survey had gains in the medium gain range. Hake defines a medium gain class as having a <g> between 0.3 and 0.7, where students' absolute gains on the FCI were between 30% and 70% of the maximum possible gains, and a low gain class as having a <g> below 0.3, with students' absolute gains on the FCI less than 30% of the maximum possible gain. While a normalized gain of 0.32 is not a high gain for an interactive engagement class, Hake's study did report similar gains for some of the interactive engagement classes surveyed and this is well above the average gain of 0.23 reported for traditional physics courses in Hake's study.

Coletta and Phillips (2005) suggest that there may be a correlation between normalized gains on conceptual surveys like the FCI and pre-test scores. They suggest that students with low pre-test scores also show low normalized gains on the FCI. They suggest that, due to this correlation, interactive engagement classes with low to medium gains are not necessarily less effective than classes with higher gains if the student pre-test scores are particularly low, less than 40%, and that student population may affect both normalized gains on diagnostic tests like the FCI and also on course grades and exam scores. The observations of relatively low student gains in physics content

knowledge in this study match their results, with student pre-test scores averaging 30%. Lasry, Mazur, and Watkins (2008) observed a similar effect, with their study of student gains in interactive engagement classes at Harvard University and a two-year college. They separated students at the two-year college into two groups, those with low pre-test scores (<40%) and those with high pre-test scores (>40%). The Harvard class was not considered in this analysis, since no student there scored below 70% on the FCI pre-test. Similar results were obtained, with students in the low pre-test group showing significantly lower normalized gains than those in the high pre-test group. This suggests that student prior knowledge and preparation may play a significant role in learning gains, even in an interactive engagement course, and that students with less prior knowledge or preparation may need more focused interventions. This may also partially explain the relatively low normalized gains observed in this study. Given the similar results observed in other studies, the observed gain of 0.32 here is a good outcome, considering the very low student pre-test scores. In addition to this, the low pre-test group in this study had an average normalized gain of 0.27, which is comparable to the best performing traditional classes in Hake's study. This indicates that, even for the low pre-test group, the interactive engagement interventions were effective at promoting student learning of physics.

However, while student prior knowledge may play a role, it does not seem to completely explain the relatively low gains observed in this course. The gains for the low pre-test students were lower than that reported by both Lasry, et. al. (2008) and Coleta and Phillips (2005). In addition, Pollock (2004) performed a study on a class with similar interactive engagement features as that in this study, albeit with a separate recitation

section, and observed high normalized gains despite low pre-test scores on the Force-Motion Concept Evaluation (FCME). Hake (1998) and others suggest that the implementation of interactive strategies can also affect student learning in reformed courses (West, et. al., 2012). This may have been a factor in this study as well, as the instructor had limited experience with interactive engagement strategies before teaching the course. Turpen and Finkelstein (2009) also provide evidence for this hypothesis, showing that varying implementations of interactive methods can affect students' experiences and learning gains in a course.

Views of physics. In this study, students' views of physics remained roughly stable during instruction, overall and in the views categories examined. In fact, the only statistically significant difference in student views found in this research between pre- and post-instruction was for the views category of confidence, with students becoming very slightly less confident in their abilities to learn physics or solve problems during the term. This relative stability in student views was somewhat unexpected, given the prevalence in the literature of research showing that student views become less favorable during instruction, particularly as the course was not designed to give special attention to students' views of physics and interactive engagement methods were not used in the separate, departmentally run laboratory portion of the course, which had the potential to send mixed messages to students about what aspects of learning were most important. However, the lack of decline in student views is a better result that was expected, given the trend in the physics education literature of students' views of physics becoming less expert-like after instruction, even in reformed classes.

One common theme in physics education research is that students' views of physics commonly decrease, or become less "expert-like," between pre- and post-instruction surveys for both traditionally taught and interactive engagement introductory physics courses (Adams, et. al., 2006; Redish & Hammer, 2009; Redish, Saul, & Steinberg, 1998). Redish and Hammer (2009) argue that this is at least partly due to what they call an "implicit curriculum" in introductory physics classes (p. 629). This implicit curriculum includes assumptions made by instructors, including that students know how to think about physics and how to learn physics while doing ordinary class activities like homework problems or reading textbooks. Regardless of the good intentions of instructors, Redish and Hammer (2009) state that students often discover that rote memorization and novice approaches to learning lead to more success in introductory physics courses. This can lead to students' views of physics becoming less expert-like over the duration of the course.

In addition to this, there is evidence that students do understand what expert-like beliefs are, but that they do not hold these beliefs themselves. Gray, Adams, Weiman, and Perkins (2008) performed a split-task survey using the CLASS in a pre-post test design and found that students' scores were highly "expert-like" and stable both pre- and post-instruction when asked to respond as they thought a physicist would. However, when asked to respond with their own personal views, students' responses were overall less favorable initially and declined between the pre-and post-tests. Their conclusion is that students understand what expert views of physics are, but that they do not believe this themselves. Gray, et. al. (2008) also speculate somewhat about the possible reasons for this difference between students' actual views of physics and what they believe are

expert views. Some possible reasons given are that students believe that physicists are more interested in physics and are aware of the link between physics and the real world than students, that typical problems that students see in introductory classes are not realistic or relatable for students, and that physicists' greater expertise would influence their beliefs. However, they caution that these reasons are only speculation and that further research needs to be done on this topic.

Another possible explanation for stability or a decline in students' views of physics is response-shift bias. Response-shift bias is a phenomenon where students' pre-test results on views surveys can sometimes be artificially high because students' perceptions of their abilities regarding a subject are unrealistic. At post-test, students are more familiar with the subject and are more realistic in their later ratings, resulting in stable or even declining views scores (Howard & Dailey, 1979). Drennan and Hyde (2008) suggest that students' feelings of confidence in their abilities and other self-efficacy beliefs may be particularly susceptible to response-shift bias. In order to test whether response-shift bias is an effect, they recommend a retrospective pre-test design where students are asked to rate their pre-instruction views at the same time as the post-test.

While most physics education research shows that students' views of physics become less favorable during instruction, there have been some studies that show students' views becoming more favorable or remaining neutral after instruction. Pollock (2004) and Milner-Bolotin, Antimirova, Noack, and Petrov (2011) found that students' views remained approximately the same between pre- and post-instruction surveys in interactive engagement courses. Milner-Bolotin, et. al. (2011) even reported an increase

in favorable views on the CLASS in the views category of real-world connection, or how students see physics as being relevant in the "real world." Redish and Hammer (2009) report that in a study of a completely redesigned introductory physics class, students' views of physics became significantly more favorable between pre- and post-tests. They attribute this to the course being designed to pay special attention to students' epistemologies and views during every part of the class and integrating the interactive engagement activities into every aspect of the course, including lectures, recitations, and laboratories.

Walker, Cotner, Baepler, and Decker (2008), in a study of an introductory biology course with a similar population as that in this research, suggest that students' confidence may decrease in an interactive engagement classroom because students are exposed to fewer instances of direct instruction. Instead, in the interactive engagement course, students are more often required to reason through questions and problems and are not always "given" the correct answers from authorities or experts. This uncertainty translates to a loss of confidence in their abilities, although Walker, et. al. (2008) show that these students do perform better, both conceptually and at problem solving, than students in a traditionally formatted course. This suggests that students are not always accurate judges of their own abilities. A similar effect could explain students' relative decline in confidence in their abilities in this study.

Correlations between student content knowledge and views of physics. Students' pre-instruction views of physics have been shown in the physics education research literature to be positively correlated with students' conceptual gains in physics content knowledge (Elby, 2001; Milner-Bolotin, et. al., 2011; Redish and Hammer,

2009). Elby (2001) suggests that this is because students' views of physics affect their "mindset, metacognitive practices, and study habits" (p. S64). This research found a similar correlation between students' normalized gains and pre-instruction CLASS scores. Although this correlation was not very strong, it was statistically significant, with students whose views of physics were initially favorable showing higher normalized gains than students whose views were initially unfavorable. This correlation also held true for students' post-instruction CLASS scores, which is not surprising given the relatively flat nature of students' views of physics during the course of this study.

Redish and Hammer (2009) also showed a much more pronounced correlation with students' post-instruction views of physics and conceptual understanding, with both students' views of physics and conceptual understanding improving between pre- and post-tests in their course. They suggest that this indicates that instructors should pay explicit attention to students' views of physics and learning physics throughout the course and make tending to students' views explicitly part of the curriculum by including metacognitive questions in graded activities and integrating the interactive engagement activities more smoothly into every part of the course. That was not an explicit part of the instruction in this study. Students' views of physics were not explicitly addressed in every part of this class. Instead, instruction was more focused on the explicit implementation of the interactive engagement and students' conceptual learning. This may have contributed to the slight decrease in student confidence observed in this study.

Instructional Strategies to Support Student Learning and Features of Course Design.

Instructional strategies to support student learning. The instructional strategies that were an integral part of all the course design features used in this course include giving students opportunities to work together to share their ideas, explain their reasoning, revise their ideas, and apply their reasoning to various situations and problems in introductory physics, as well as providing students with instructor interaction and feedback. Educational research points to these strategies and being integral to promoting and supporting student learning (NRC, 2005). However, research in physics education indicates that the effect of each of these supports is very difficult to isolate and that it is the interaction of all of them together that most strongly affects student learning and views (Pollock, 2004). This is also supported by this research, which showed no correlation between student FCI gains or CLASS scores and students' statements about whether the individual strategies were helpful by themselves or in the context of the course activities. However, there was a significant correlation between students' responses to whether all of the instructional strategies together were helpful and their FCI normalized gains, which gives credence to the idea that it is the interaction between these strategies and their context that provides the most support for student learning.

Students, in both open-ended surveys, overwhelmingly reported that working together and discussing their ideas during all of the class activities was beneficial to helping them learn physics concepts. This is consistent with other research that suggests that allowing students to construct their own understandings of concepts cooperatively leads to more learning than simple transmission of information (Glaser, 1990; Nicol &

Boyle, 2003; NRC, 2005). However, students also reported some instances where they found working together to be confusing or counter-productive. These instances occurred most often when all students in the group were unsure of their ideas or did not know where to begin. For this course, these problems were most often issues during tutorials, although some students reported similar problems in other activities as well. This effect was also noted by Nicol and Boyle (2003) during Peer Instruction activities, and they suggest that leading a whole class discussion of the concept or problem before having students work in small groups can help to mitigate this somewhat.

Redish and Hammer (2009) suggest that a meta-cognitive approach to student learning, where the process of learning is emphasized as much as the content being learned, can lead to improved outcomes in terms of student scores on conceptual tests and student views of physics. Requiring students to explain their reasoning, both verbally to each other and in writing, fits with this approach. This allows students to think more deeply about what they know about a physics concept, but also about how they know it and why it must be true. In addition, providing students with opportunities to revise their understanding allows them to identify their own misconceptions and work together to construct a more correct understanding of physics concepts.

Features of course design. This course was taught using interactive engagement methods in every part of instruction except the departmentally run laboratories. The specific course features used in this class include Peer Instruction, Tutorials, and Interactive Demonstrations. Since there were no separate recitation sections for this course, all activities took place during the large enrollment lecture meetings. All of these activities required students to work together sharing their ideas, explain and justify their

reasoning in writing and verbally to each other, and they were given opportunities to revise, and maybe change, their ideas in each activity.

Peer Instruction. In this class, Peer Instruction activities consisted of students answering a challenging conceptual question on their own, discussing their reasoning with their peers, and then answering the same question again. In most cases, the percentages of students answering correctly increased dramatically at the second polling, in agreement with other implementations of Peer Instruction (Crouch & Mazur, 2001; Mayer, et. al., 2009; Mazur, 1997; Nicol & Boyle, 2003). The second polling was generally followed by a whole class discussion of the concept, with individual students explaining their reasoning for both correct and incorrect answers to the entire class, followed by instructor explanation of the concept and the correct answer. This provided the students with multiple opportunities to share ideas, explain their reasoning, and often to revise their thinking about various concepts. Results of the student interviews and open-ended surveys conducted in this study indicated that students found activities using the clicker system to be the most helpful to their learning. When asked directly, the students who participated in interviews mentioned these activities as being generally helpful in the context of sharing their ideas, explaining their reasoning, and revising their ideas about concepts.

Mayer, et. al. (2009) showed that the types of questions asked matter with respect to student learning, with conceptual questions better supporting student learning than factual or recall type questions. This is particularly true with students are asked questions about topics that are related to, but not the same as, topics that are covered in lecture. In addition to this, Turpen and Finkelstein (2009) showed that the amount and type of

instructor-student and student-student interaction that occurs during Peer Instruction influences students' experiences of the course and their learning gains on tests of conceptual understanding. They found that students in classes where instructors give students up to five or more minutes to discuss their answers and explain their reasoning to each other during the discussion phase of Peer Instruction performed better than students who were only given two to three minutes to discuss their ideas with each other. Also, they found that students who were given more time to discuss and whose instructors interacted with them during this time outperformed both groups. Smith, Wood, Krauter, and Knight (2011) performed a study in introductory biology classes, with student populations similar to this study, and found that combining student discussions with instructor explanations on Peer Instruction type questions lead to the most student learning of biology concepts.

Interactive Demonstrations. In this class, the interactive demonstration activities followed a modified predict, observe, explain format using the clicker system, where students first predicted the outcome of a demonstration, discussed their predictions with each other, predicted again, and then watched the demonstration, followed by a whole class discussion. As with the Peer Instruction activities, students were provided with many opportunities to share ideas with each other, explain their reasoning, and revise their ideas during the interactive demonstrations. Unlike the Peer Instruction activities, however, students did not often cite these instructional strategies directly when asked about the demonstrations during interviews or on the open-ended survey questions. Instead, students tended to separate the observation of the demonstration from the predictions and discussion when asked about these activities, classifying the prediction

and discussion as part of the Peer Instruction, or "clicker," activities and the actual performed demonstration as discrete events rather than an integrated whole. However, students did say that they found the demonstrations to be helpful to improving their understanding of physics concepts almost as often as the Peer Instruction activities.

Crouch, Fagen, Callan, and Mazur (2004) studied the use of classroom demonstrations in an introductory physics course aimed primarily at pre-medical students. They compared the use of demonstrations alone, where students passively watched a demonstration accompanied by instructor explanations with both interactive demonstrations where students predicted the outcome before seeing the demonstration and hearing the instructor explanation and interactive demonstrations where students predicted the outcome, observed the demonstration, and discussed the results with each other before hearing the instructor explanation. They found that both interactive groups were significantly better than the non-interactive group and that the discussion group was marginally better than the predict-only group at later recalling and explaining the results of the demonstration.

Milner-Bolotin, Kotlicki, and Reiger (2007) performed a study of interactive demonstrations and reported that the conflict between student predictions, which often elicit common misconceptions, and the actual results of a demonstration can cause discomfort and undermine student confidence in their own abilities. They state that this could especially be a problem in large enrollment classes, where "students have to learn to self-regulate their learning, and motivation is a stepping stone in this process" (p. 47). This effect could have been partially responsible for the slight decrease in student confidence as measured by the CLASS pre- and post-tests and observed in student

interviews in this study. However, the results of interviews and open-ended written surveys in this study found that students viewed the pre-demonstration predict and explain portions of the interactive demonstration activities as completely separate from the observed demonstration and discussion and explanation portions of the activity. The students in this study did not report any conflict or painful learning process with these interactive demonstrations. Most students reported that the demonstrations were very helpful to their leaning and, while some complained about making predictions of the results beforehand, most of the complaints were because students did not see the point in making predictions when they were going to see the results in a short time anyway.

Tutorials. The use of tutorials in introductory physics classes are thought to be beneficial to student learning because they allow students to work together to reason through a new, often difficult, concept while explicitly requiring them to explain their reasoning to each other and in writing and to revise their ideas multiple times during the activity. The tutorials used in this study were a combination of *Open Source Tutorials in Physics Sense-making* (Scherr & Elby, 2006) and *Tutorials in Introductory Physics* (McDermott & Shaffer, 2002). In almost all cases, tutorials were modified slightly to make them easier to use in the large enrollment course.

The results of interviews and open-ended surveys in this study indicate that students had mixed feelings about the use of tutorials. Many students complained that they did not like doing tutorials and that the activities were difficult. Students were frustrated by questions that they felt were repetitive and with being explicitly asked to re-think through certain answers in different ways. They specifically felt that the uncertainty inherent in some of the tutorial activities was unsettling for them, especially

since they were not provided with a set of correct answers to the tutorial questions. However, many of these same students also stated that they found the tutorials helpful to their understanding of physics concepts and that they were valuable activities in the course. The uncertainty that students were especially uncomfortably with could have also contributed to the slight decrease in student confidence that was evident between pre- and post-instruction CLASS scores and student interviews.

Finkelstein and Pollock (2005) reported similar student attitudes to tutorials. They performed a study on the implementation of the *Tutorials in Introductory Physics* in several large enrollment introductory physics classes with separate recitation sections. They found that overall students found the tutorials useful, but that they were uncomfortable with the lack of definitively correct answers and that they felt that the tutorial activities were unnecessarily challenging. At the same time, their students reported that they did enjoy working on the tutorials in groups and felt that it was beneficial to their understanding. They hypothesize that one reason for this contradiction in students' feelings about the tutorial activities is a difference between students' expectations about learning and the environment in a reformed class using tutorials. They recommend that instructors who are implementing interactive methods such as tutorials make their expectations of students explicit and that the implementation of these activities must be consistent across all aspects of the course. Especially important is that tutorial activities are not undermined by well-meaning but untrained teaching assistants and lecture assistants who want to help students by giving the "right" answers to student questions rather than encouraging students to reason through and discover these for themselves.

Most of the research into the use of tutorials in introductory physics has been done in smaller recitation sections. Slezak, Koenig, Endorf, and Braun (2011) performed a study of the use of the *Tutorials in Introductory Physics* in different instructional settings, including an online only implementation where students worked on their own and small group recitations with varying levels of instructional support. They found that the role of the instructor in implementation of tutorials is very important to student learning. Students in the small group recitations with high levels of instructor support during tutorials performed significantly better on tests of conceptual understanding than students in the small group recitations with limited instructor support or in the online implementation with students working on their own. However, they note that students who completed the tutorials online reported greater satisfaction with the activity, as they felt that they had received a definitive set of answers to the tutorial questions, even though they performed significantly worse on tests of conceptual understanding than any of the other groups. This gives more evidence to the supposition that even though students perform better when they must reason through questions and concepts, they rate their comfort with knowing the "right" answers more highly than activities that cause them discomfort and a lack of confidence (Walker, et. al., 2008). This effect was also observed in this study, with students complaining in interviews and open-ended written surveys that the lack of a definitive set of answers to the tutorial activities was one of their least favorite aspects of the activity.

Summary

It has been shown in the physics education literature and in this study that implementing interactive engagement that gives students opportunities to work together

and share their ideas about physics with each other, to explain their reasoning in writing and verbally to each other and instructors, to revise their ideas, and to apply their reasoning to solve problems and understand concepts can lead to improved student conceptual understanding of physics, although few studies have also shown improved student views of physics. However, in this study, some issues with the implementation of the interactive engagement strategies that may have mitigated student gains in understanding of physics concepts and contributed to a decline in student confidence in their abilities have been identified.

There were some aspects of the implementation of the interactive engagement activities in this study that may have affected students' gains in conceptual understanding. Part of this study was to investigate whether it was possible for students in a large enrollment interactive engagement class with no separate recitation could obtain gains in conceptual understanding comparable to that reported in the literature for a similar class with the smaller recitation sections. While this study clearly shows that this is possible for students in this type of class to perform better than a traditional lecture with separate recitations, much higher gains have been reported in the literature. One issue may have been that, while the instructor of this course was an experienced teacher, this instructor had only limited experience with interactive methods of teaching. In addition, due to the large class size and a single instructor being responsible for keeping over 100 students on task during tutorials, as well as providing guidance and answering questions while students worked on tutorials or during clicker question discussion periods, it was difficult to provide students with focused instructor-student or instructor-small group interactions. Institutional support in form of professional development for

lead instructors in these teaching methods as well as the provision of well-trained graduate teaching assistants or undergraduate lecture assistants to help the lead instructor during the implementation of tutorials would help tremendously in giving students more opportunities to have conversations and engage in dialogue with experts and exposing them to expert-like knowledge and reasoning.

Another issue that was found in this study was that, while overall students' views of physics remained relatively flat through the course, students' confidence in their abilities to understand physics and solve problems decreased slightly but significantly between the CLASS pre- and post-tests and on interviews. There are some strategies that could be used to help students increase their confidence in their abilities to learn and do physics. Since, according to Walker, et. al. (2008), students' lack of confidence comes from their uncertainty about the "right" answer or method for solving problems that comes with a class whose main focus is on students' building their own understanding rather than relying on information being given to them from authority, one way to help students deal with this uncertainty is to show them results of physics education research that shows that students in these classes do perform better than students in traditional classes. In addition, students can be provided with more focused and timely feedback on written or verbal work to show them that they are learning appropriately. However, in a large enrollment class, particularly one without a separate recitation section, this extra feedback can be logistically difficult and will require support from departments and colleges in the form of extra trained teaching assistants or lecture assistants to provide this support during class meetings and for extra grading support.

Implications

This study points to some recommendations for implementation of interactive engagement methods in a large enrollment, introductory physics class without a separate recitation section. It is recommended that interactive methods are used in introductory physics courses, as these methods clearly lead to greater student understanding of physics. However, these methods are much more time intensive for instructors than traditional methods, require some skill in implementation, and require much more institutional support than traditional classes.

If interactive methods are to be implemented in introductory classes, institutions should provide support in the form of teaching or lecture assistants to help during class time with answering student questions and providing feedback and to help with more detailed grading of student work. In addition, instructors and teaching and lecture assistants would benefit from professional development opportunities and training in implementing and using interactive teaching methods. Institutions should encourage the use of interactive engagement methods by promoting a culture of teaching in departments and colleges where introductory courses are owned by departments rather than individual instructors, so that students receive consistent instruction in these courses, no matter which section they are enrolled in. Institutions should also consider teaching with interactive engagement when evaluating instructors for tenure and promotion. This type of instruction requires more from instructors in terms of time and preparation than traditional instruction and this extra effort should be valued by institutions.

Instructors who wish to implement interactive methods in their introductory classes should not be afraid to start slow, only incorporating one or two activities, such as

Peer Instruction and interactive demonstrations, consistently throughout a term and gradually working their way up to full implementation. However, instructors should be consistent with their implementation, not allowing students to avoid participating in class activities in favor of more passive learning and not falling back onto the use of traditional lectures partway through the term. Instructors should also explicitly communicate with students about various aspects of the of the course, including the instructional strategies and hold students responsible for these activities through assessments that require them to explain their reasoning and apply their understanding of various concepts (Redish & Hammer, 2009).

Future Directions

Future research that examines the effects of continued and improved implementation of interactive methods with a consistent group of instructors and similar student populations over time on student conceptual understanding and views of physics is recommended. This study reports findings on the use of interactive methods in a large enrollment introductory college physics class without a separate recitation section that are favorable. Students improved their conceptual understandings, as measured by a pre- and post-instruction administration of the Force Concept Inventory. Students' views of physics also remained relatively stable through the duration of the term, in contrast with other studies that showed students' views became less expert-like between pre- and post-instruction (Adams, et. al., 2006; Redish & Hammer, 2009; Redish, Saul, & Steinberg, 1998). Response-shift bias may partly explain the results around students' views of physics and future research should investigate this possibility. Although this study did show normalized gains on the FCI for students within the range of that reported for other

interactive engagement courses, they were on the low end of that range. This could be partly due to student population, but also is at least partly due to the lack of experience of the instructor with these methods. The instructor for this course is an experienced teacher, but only has limited experience with interactive methods and therefore there were some issues with the implementation. Nevertheless, this study adds to the evidence that even instructors with limited or no experience with these methods can implement them reasonably successfully and improve student understanding of physics.

Another possible avenue for future research is to try to isolate the effects of each of the instructional strategies identified in this study to investigate which are the most important to student learning, particularly in a large enrollment class, or whether the interaction of them together is the most important aspect. This study identified several instructional strategies that support student learning that were part of each of the interactive course activities used. These strategies include allowing and encouraging students to work together during class time to discuss their ideas with each other, explain their reasoning verbally to each other and in writing, revise their ideas when appropriate, and apply their reasoning to various problems, as well as providing instructor feedback and instructor-student interactions during class time. It was not possible in this study to isolate the effects of any one of these instructional strategies, but the results support the idea reported in the literature that it is the interaction of these strategies together that correlates with improved student understanding of physics concepts.

Conclusion

This study investigated the use of interactive engagement method in a large enrollment, introductory college physics course without a separate recitation section.

Specifically, this study investigated whether the use of these methods led to improved student scores on a test of conceptual understanding and more expert-like views of physics in such a class. Previous research in physics education has focused mainly on large enrollment classes that also had a separate, small enrollment recitation section where students could work cooperatively on tutorial activities or group problem solving and has shown that these methods can lead to improved student conceptual in classes with that format. This research has shown that these methods can be beneficial to students in an introductory physics course without a separate recitation section. However, this research agrees with previous studies in the literature that suggest that the most helpful aspects of these activities cannot be isolated, but that it is instead the interaction of the various instructional strategies that lead to student conceptual learning gains and improved views of physics. In light of these findings, it is suggested that interactive engagement methods be adopted in introductory college physics classes, even those without a separate recitation section. This adoption will require institutional changes in terms of instructor support for using these methods and a change in the culture around tenure and promotion to value this type of instruction on par with service and research. Future directions for research include investigation of response-shift bias as a possible factor in students' views of physics and investigation of whether the effects of the instructional strategies on student learning can be isolated.

References

Adams, W. K., Perkins, K. K, Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. (2006). New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey. *Physical Review Special Topics—Physics Education Research, 2* (1), 010101. doi: 10.1103/PhysRevSTPER.2.010101.

Augustine, N. R. (2007) Is American falling off the flat earth? National Academy of Sciences Press. Washington, D.C.

Barrett, S. E., Fatholahzadeh, B., Harrison, D., & Hazari, Z. (2012). Electromagnetism unit of an introductory university physics course: The influence of a reform-based tutorial. *Journal of College Science Teaching, 41(6),* 40.

Blasco-Arcas, L., Buil, I., Hernandez-Ortega, B., & Sese, F. (2013). Using clickers in class: The role of interactivity, active collaborative learning and engagement in learning performance. *Computers and education, 62,* 102-110.

Brewe, E., Kramer, L., & O'Brien, G. (2009). Modeling instruction: Positive attitudinal shifts in introductory physics measured with CLASS. *Physical Review Special Topics Physics Education Research* 5, 013102. doi: 10.1103:PhysRevSTPER.5.013102

Brownstein, E., & Klein, R. (2006). Blogs: Applications in science education. *Journal of College Science Teaching, 35(6),* 123-136.

Clark, K. (2009, January 27). The recession hits college campuses. *US News and World Report*. http://www.usnews.com/articles/education/2009/01/27/the-recession-hits-college-campuses.html

Coletta, V., & Phillips, J. (2005). Interpreting FCI scores: Normalized gain, pre-instruction scores, and scientific reasoning ability. *American Journal of Physics, 73(12)*, 1172-1182.

Cooper, J., & Robinson, P. (2000). The argument for making large classes seem small. *New Directions for Teaching and Learning*, *81*, 5-15

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

Crouch, C., Fagen, A., Callan, J., & Mazur, E. (2004). Classroom demonstrations: learning tools or entertainment? *American Journal of Physics, 72(6),* 835-838.

De la Garza, J., & Alarcon, H. (2010). Assessing students' attitudes in a college physics course in Mexico. In Singh, C., Sabella, C., & Rebello, S. (Eds.) *AIP Physics Education Research Conference Proceedings*, 129-132.

DeHaan, R. L. (2005). The impending revolution in undergraduate science education. (*Journal of Science Education and Technology, 14*, 253-269

Denker, K. (2013). Student response systems and facilitating the large lecture basic communication course: Assessing engagement and learning. *Communication Teacher, 27(1),* 50-69.

Deslauriers, L., Schelew, E., & Weiman, C. (2011). Improved learning in a large-enrollment physics class. *Science, 332*, 862-864.

Ding, L., Chabay, R., Sherwood, B., & Beichner, R. (2006). Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment. *Physical Review Special Topics: Physics Education Research, 2*. doi: 10.1103/PhysRevSTPER.2.010105.

Drennan, J., & Hyde, A. (2008). Controlling response shift bias: the use of the retrospective pre-test design in the evaluation of a master's programme. *Assessment & Evaluation in Higher Education, 33(6),* 699-709.

Duda, G., & Garrett, K. (2008). Blogging in the physics classroom: A research-based approach to shaping students' attitudes toward physics. *American Journal of Physics, 76(11),* 1054-1065.

Duit, R., Niedderer, H., & Schecker, H. (2007). Teaching physics. In Abell, S., & Lederman, N. (Eds.), *Handbook of Research on Science Education*, (75-102). New Jersey: Lawrence Erlbaum Associates.

Elby, A. (2001). Helping physics students learn how to learn. *Physics Education Research: American Journal of Physics Supplement, 69(7),* S54-S64.

Elby, A., Frederiksen, J., Schwarz, C., & White, B. (2001). The idea behind EBAPS. http://www2.physics.umd.edu/~elby/EBAPS/idea.htm

Epstein, J. (2010). Graduation gaps for science majors. *Inside Higher Ed*. http://www.insidehighered.com/news/2010/02/17/stem

Eylon, B., & Reif, F. (1984). Effects of knowledge organization on task performance. *Cognition and Instruction, 1,* 5-44.

Ferdig, R., & Trammel., K. (2004, February 1). Content delivery in the blogosphere. *THE Journal.* http://www.thejournal.com

Ferenstein, G. (2010, March 1). How Twitter in the classroom is boosting student engagement. *Mashable/Social Media.* http://mashable.com/2010/03/01/wtitter-classroom/

Finkelstein, N., & Pollock, S. (2005). Replicating and understanding successful innovatins: Implementing tutorials in introductory physics. *Physical Review Special Topics: Physics Education Research, 1,* 010101. doi: 10.1103:PhysRevSTPER.1.010101.

Fry, R. (2009). College enrollment hits all time high, fueled by community college enrollment. *Pew Research Center.* http://pewsocialtrends.org/pubs/747/college-enrollment-hits-all-time-high-fueled-by-community-college-enrollment-surge#prc-jump.

Getinet, T. (2012). Effect of instructional interventions on student learning gains: An experimental research. *Latin American Journal of Physics Education, 6(2),* 187-195.

Gire, E., & Jones, B. (2009). Characterizing the epistemological development of physics majors. *Physical Review Special Topics: Physics Education Research, 5.* doi: 10.1103/PhysRevSTPER.5.010103.

Glaser, R. (1990). The re-emergence of learning theory within instructional research. *American Psychologist. 45*, 29-39.

Glenn, D. (2010, March 7). Big classes encourage experiments in teaching. *Chronicle of Higher Education*. http://chronicle.com/article/Bigger-Classes-Encourage-Ex/64525/

Godoy, P., Benegas, J., & Pandiella, D. (2012). Active learning of physics: Synergy of teaching strategies. *Latin American Journal of Physics Education, 6(S1),* 99-104.

Gray, K., Adams, W., Weiman, C., & Perkins, K. (2008). Students know what physicists believe, but they don't agree: A study using the CLASS survey. *Physical Review Special Topics: Physics Education Research, 4*, 020106.

Guy, R., Lownes-Jackson, M. (2012). Assessing the effectiveness of web based tutorials using pre- and post-test measurements. *Interdisciplinary Journal of E-learning and Learning Objects, 8*, 15-38. http://www.ijello.org/Volume8/IJELLOv8p015-038Guy0793.pdf

Guy, R., & Lownes-Jackson, M. (2013). Web-based ututorials and traditional face to face lectures: A comparative analysis of student performance. *Issues in Informing Science and Information Technology, 10,* 241-259.

Hake, R. (1998). Interactive engagement versus traditional methods: A six thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66(1),* 64-74.

Halloun, I., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53(11),* 1043-1055.

Halloun, I., & Hestenes, D. (1996). Views About Science Survey. *Annual Meeting of the National Association for Research in Science Teaching*, St. Louis, MO. ERIC Document ED394840.

Halloun, I., & Hestenes, D. (1998). Interpreting VASS dimensions and profiles for physics students. *Science and Education, 7(6),* 553-577.

Handelsman, J., Ebert-May, D., Beichner, R., Bruns, P., Change, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S., & Wood, W. (2004). Scientific teaching. *Science, 304*, 521-522.

Hazari, Z., Tai, R. H., & Sadler, P. M. (2007). Gender differences in introductory university physics performance: The influence of high school physics preparation and affective factors. *Science Education, 91*, 847-876

Hestenes, D., & Halloun, I. (1995). Interpreting the Force Concept Inventory. *The Physics Teacher, 33*, 502-506.

Hestenes, D., & Wells, M. (1992). A Mechanics Baseline Test. *The Physics Teacher, 30,* 159-166.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141-166.

Howard, G., & Dailey, P. (1979). Response-shift bias: A source of contamination of self-report measures. *Journal of Applied Psychology, 64(2),* 144-150.

Ivie, R., & Nies Ray, K. (2005). Women in Physics and Astronomy, 2005. *American Institute of Physics Report*. http://www.aip.org/statistics/trends/gendertrends.html

Junco, R., Heibegert, G., & Loken, E. (2011). The effect of Twitter on college student engagement and grades. *Journal of Computer Assisted Learning, 27(2),* 119-132.

Koballa, T., & Glynn, S. (2007). Attitudinal and motivational constructs in science learning. In Abell, S., & Lederman, N. (Eds.), *Handbook of Research on Science Education*, (75-102). New Jersey: Lawrence Erlbaum Associates.

Kortemeyer, G. (2007). Correlations between student discussion behavior, attitudes, and learning. *Physical Review Special Topics: Physics Education Research, 3*. doi: 10.1103/PhysRevSTPER.3.010101.

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer instruction: From Harvard to the two-year college. *American Journal of Physics, 76(11),* 1066-1069.

Lee, J. J. (2008). Size matters: An exploratory comparison of small and large class university lecture introductions. *English for Specific Purposes, 28*, 42-57.

Leonard, W. (2000). How do college students best learn science? *Journal of College Science Teaching, 29*, 385-388.

Lewis, S., & Lewis, J. (2008). Seeking effectiveness and equity in a large college chemistry course: An HLM investigation of Peer Led Guided Inquiry. *Journal of Research in Science Teaching, 45(7),* 794-811.

Lin, X. D., & Lehman, J. (1999). Supporting learning of variable control in a computer based biology environment: Effects of prompting college students to reflect on their own thinking. *Journal of Research in Science Teaching, 36(7),* 837-858.

Lindenfeld, P. (2002). Format and content in introductory physics. *American Journal of Physics, 70(1),* 12-13.

Lindsey, B., & Liu, A. (2013). Comgining two reform curricula: An example from a course with well prepared students. *American Journal of Physics, 81(7),* 545.

Lindsey, B., Hsu, L., Sadaghiani, H., Taylor, J., & Cummings, K. (2012). Positive attitudinal shifts with the Physics by Inquiry curriculum across multiple implementations. *Physical Review Special Topics Physics Education Research. 8*, 010102. doi: 10.1103/PhysRevSTPER.0.010102

Lising, L., & Elby, A. (2005). The impact of epistemology on learning: A case study from introductory physics. *American Journal of Physics, 73(4),* 372-383.

Maloney, D., O'Kuma, T., Hieggelke, C., & Van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *Physics Education Research, American Journal of Physics Supplement, 69(7),* S12-S23

May, D., & Etkina, E. (2002). College physics students' epistemological self-reflection and its relationship to conceptual learning. *American Journal of Physics, 70(12)*, 1249-1272

Mayer, R., Stull, A., DeLeeuw, K., Almeroth, K., Bimber, B., Chun, D., Bulger, M., Campbell, J., Knight, A., & Zhang, H. (2009). Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. *Contemporary Educational Psychology, 34,* 51-57.

Mazur, E. (1997). *Peer Instruction: A User's Manual.* New Jersey: Prentice Hall.

McDermott, L. (1984). Research on conceptual understanding in mechanics. *Physics Today, 37(7),* 24-32.

McDermott, L. & Shaffer., P. (2002). *Tutorials in Introductory Physics*. Prentice Hall, New Jersey.

Mellema, S. (2001). A physics lecture for the 21st century. *Physics Education, 36,* 306-310.

Meltzer, D., & Manivannan, K. (2002). Transforming the lecture hall environment: The fully interactive physics lecture. *American Journal of Physics, 70,* 639-654

Mestre, J. P. (2001). Implications of research on learning for the education of prospective science and physics teachers. *Physics Education, 36,* 44-51.

Michael, J. (2006). Where's the evidence that active learning works? *Advances in Physiology Education, 30(4),* 159-167.

Millikan, R. A. (1903). *Mechanics, Molecular Physics, and Heat: A 12 Weeks College Course*. Boston: Guinn & Co.

Milner-Bolotin, M., Antimirova, T., Noack, A., & Petrov, A. (2011). Attitudes about science and conceptual physics learning in university introductory physics courses. *Physical Review Special Topics: Physics Education Research, 7*, 020107. doi: 10.1103/PhysRevSTPER.7.020107

Milner-Bolotin, M., Kotlicki, A., Reiger, R. (2007). Can students learn from lecture demonstrations?: The role and place of interactive lecture experiments in large introductory science courses. *Journal of College Science Teaching, 36(4),* 45-49.

National Research Council. (1999). *How People Learn: Bridging Research and Practice.* Donovan, M., Bransford, J., & Pelegrino, J. (Eds.), Washington DC: National Academies Press.

National Research Council. (2000). *How people learn: Brain, mind, experience, and school*. Committee on Developments in the Science of Learning. Bransford, J. D., Brown, A. L., and Cocking, R. R. (Eds.). Washington, DC: National Academies Press.

National Research Council. (2005). *How students learn: Science in the classroom.* Committee on *How People Learn*. Donovan, M. S., and Bransford, J. D. (Eds.) Washington DC: The National Academies Press

Nicol, D., & Boyle, J. (2003). Peer instruction versus class wide discussion in large classes: A comparison of two interaction methods in the wired classroom. *Studies in Higher Education, 28(4),* 457-473

Otero, V., & Gray, K. (2008). Attitudinal gains across multiple universities using the Physics and Everyday Thinking curriculum. *Physical Review Special Topics Physics Education Research, 4,* 020104. doi: 10.1103/PhysRevSTPER.4.020104

Pajares, F. (2002). Overview of social cognitive theory and of self efficacy. http://emory.edu/EDUCATION/mfs/eff.html.

Perkens, K., Adams, W., Pollock, S., Finkelstein, N., & Wieman, C. (2005). Correlating student beliefs with student learning using the C-LASS. In J. Marx, P. Heron, S. Franklin (Eds). *2004 AIP Physics Education Research Conference.* AIP, Melville, NY.

Pollock, S. J., Finkelstein, N. D. (2008). Sustaining educational reforms in introductory physics. *Physical Review Special Topics—Physics Education Research, 4 (1),* 010110.

Pollock, S., & Finkelstein, N. (2013). *Impacts of curricular change: Implications from 8 years of data in introductory physics*. Manuscript submitted for publication. http://colorado.edu/physics/EducationIssues/papers/Pollock/Pollock_PERC12_paper_final_resubmitted.pdf

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93(3),* 223-231.

Redish, E. (1994). Implications of cognitive studies for teaching physics. *American Journal of Physics, 62(9),* 796-803.

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

Redish, E., Saul, J., & Steinberg, R. (1998). Student expectations in introductory physics. *American Journal of Physics, 66(3),* 212-224.

Reif, F. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought processes. *American Journal of Physics, 63(1),* 17-32.

Riffell, S., & Sibley, D. (2005). Using web-based instruction to improve large undergraduate biology courses: An evaluation of a hybrid course format. *Computers and Education, 44*, 217-235.

Sabella, M., Redish, E. (2007). Knowledge organization and activation in physics problem solving. *American Journal of Physics, 75(11),* 1017.

Sadler, P. M., & Tai, R. H. (2001). Success in introductory college physics: the role of high school preparation. *Science Education, 85*, 111-136

Savinainen, A., & Scott, P. (2002). The Force Concept Inventory: A tool for monitoring student learning. *Physics Education, 37(1),* 45.

Scherr, R., & Elby, A. (2007). Enabling informed adaptation of reformed instructional materials. In McCullough, L., Hsu, L., & Heron, P. (Eds.), *American Institute of Physics 2006 Physics Education Research Conference,* 46-49.

Seymour, E., & Hewitt, M. (1997). Talking about leaving: Why undergraduates leave the sciences. Westview Press. Boulder, Colorado

Slezak, C., Koenig, K., Endorf, R., & Braun, G. (2011). Investigating the effectiveness of the tutorials in introductory physics in multiple instructional settings. *Physical Review Special Topics: Physics Education Research, 7*, 020116. Doi: 10.1103/PhysRevSTPER.7.020116.

Smith, M., Wood, W., Krauter, K., & Knight, J. (2011). Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *CBE—Life Sciences Education, 10*, 55-63.

Tai, R., Sadler, P., & Mintzes, J. (2006). Factors influencing college science success. *Journal of College Science Teaching, 36,* 52-56.

Thornton, R., & Sokoloff, D. (1998). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics, 66(4),* 338-352.

Turpen, C., & Finkelstein, N. (2009). Not all interactive engagement is the same: Variations in physics professors' implementation of Peer Instruction. *Physical Review Special Topics: Physics Education Research, 5*. doi: 10.1103/PhysRevSTPER.5.020101.

Walker, J. D., Cotner, S. H., Baepler, P. M., & Decker, M. D. (2008). A delicate balance: Integrating active learning into a large lecture course. *CBE—Life Sciences Education, 7*, 361-367.

Walker, J., Cotner, S., Baepler, P., & Decker, M. (2008). A delicate balance: Integrating active learning into a large lecture course. *CBE—Life Sciences Education, 7*, 361-367.

Wieman, C., & Perkins, K. (2005). Transforming physics education. *Physics Today, 58(11),* 36-49.

Willoughby, S., & Gustafson, E. (2009). Technology talks: Clickers and grading incentive in the large lecture hall. *American Journal of Physics, 77(2),* 180-182.

Wittman, M., Steinberg, R., & Redish, E. (2004). *Activity Based Tutorials*. John Wiley & Sons.

Wolfman, S. (2002). Making lemonade: Exploring the bright side of large lectures. *Proceedings of SIGCSE 2002 Technical Symposium on Computer Science Education,* 257-261.

Appendix A

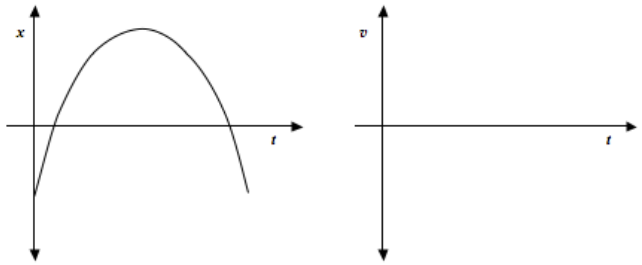
Open-ended Exam Questions with Scoring Rubrics

Exam 1

FCI Category: Kinematics

Pat and Kim are practicing for tomorrow's all star track tryouts. Pat suggests running lines. Running a line, Pat tells Kim, means running to a line at the other side of the gym, touching it, and then running back.

a. Below is a position vs. time graph of Pat's motion during one run. draw a qualitatively correct velocity vs. time graph of Pat's motion. Explain why you drew your velocity graph the way you did.



Rubric:

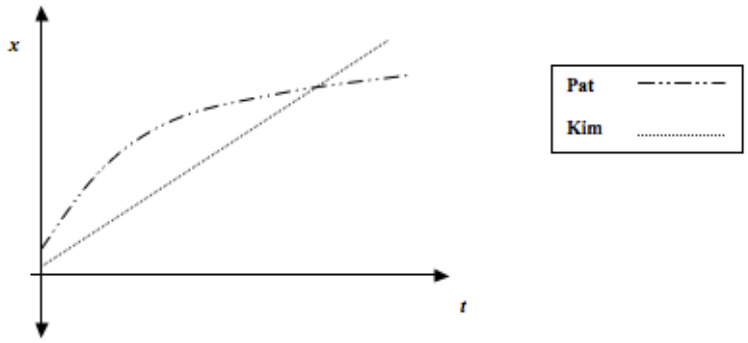
3 points: Correct graph and notes that the velocity graph is derived from the slope of the position graph at every point, with discussion of how to draw the velocity graph from this position graph (position graph starts with a large positive slope that steadily decreases to zero, then increases in the negative direction).

2 points: Correct graph and notes that the velocity graph is from the slope of the position graph at every point but with no discussion of how to draw the velocity graph from this position graph.

1 point: Incorrect graph but thoughtful and consistent explanation (i.e., graph and explanation are incorrect, but explanation/interpretation of the position graph matches the velocity graph drawn) OR a correct graph with no or a totally wrong explanation. OR Partially correct explanation (i.e., Pat changes direction with a consistent but incorrect graph).

0 points: Completely wrong with no explanation or no attempt.

b. After running a few lines, Kim suggests a long distance run. While Pat is a better sprinter, Kim has better endurance for long distances. Below is a partial graph of the motion, begun after Pat and Kim have been running for a few minutes.



i. Are there any instants where Pat and Kim are alongside one another? If so, mark the instants on the graph with a star (*) and explain your reasoning (i.e., how do you know?). If not, say so explicitly and explain your reasoning.

Rubric:

3 points: Correctly marked graph with correct explanation (Pat and Kim are alongside each other when the two graphs cross, indicating they are in the same position at the same time). Can refer to a time interval or instant in time, so long as the rest of the explanation is correct and the graph is correct.

2 points: Correctly marked graph and states that this is because the lines cross; also marks the beginning of the graph and says they start together even though they do not. OR correctly marked and reasonable but not entirely correct or complete explanation

1 points: Incorrectly marked graph with an explanation (probably also incorrect). May mix up slope and position on the graph. OR correctly marked but with no explanation

0 points: Completely wrong with no explanation or no attempt

ii. Are there any instants where Pat and Kim have the same velocity? If so, mark those instants on the graph with an X and explain your reasoning. If not, say so explicitly and explain your reasoning.

Rubric:

3 points: Correctly marked graph with correct explanation (Pat and Kim have the same velocity at that point because the slopes of their position graphs are the same at that point). Marks should be close to the same (correct) time, but they do not need to be exactly vertical (i.e., they can be slightly diagonal, but not horizontal).

2 points: Correctly marked graph with reasonable with not entirely correct or incomplete explanation (shows partial understanding, but not entirely correct).

1 point: Incorrect or no marks with an incorrect explanation (i.e., confuse the slope of the tangent line for the slope of the entire line or thinks that paths crossing means the same velocity on a position graph). Shows a thoughtful attempt but with incorrect understanding.

0 points: Completely wrong with no explanation or no attempt.

iii. Is there a time when either Pat or Kim (or both) is accelerating? If yes, circle those regions and explain your reasoning (i.e., how do you know there is acceleration from a position graph?) If not, say so explicitly and explain your reasoning.

Rubric:

3 points: Correctly marked graph with correct explanation (Only Pat accelerates because only Pat's position graph curves). Only marks the curved portion near the middle of the graph. Does not mark the steep but constant slope at the beginning of the motion or the shallow but constant slope at the end.

2 points: Marked graph and explanation shows partial but not complete understanding (i.e., circles the wrong part of the graph but understands that curve on the graph means acceleration). Does not interpret the steepness of the graph as acceleration.

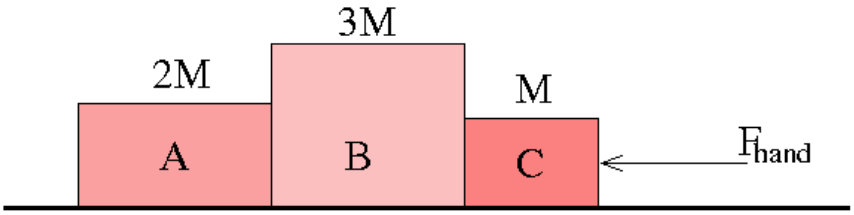
1 point: Thoughtful but incorrect answer (i.e., interprets the steepness of the position graph as higher acceleration) OR correctly marked with no explanation.

0 points: Completely wrong with no explanation or no attempt.

Exam 2

FCI Category: Dynamics 1 (Newton's Laws, Superposition Principle)

Blocks A, B, and C are being pushed across a frictionless table by a hand that exerts a constant horizontal force. Block A has a mass of 2M, block B has a mass of 3M, and block C has a mass of M.



a. Draw a free body diagram for block B. Label your force vectors to make clear the object on which each force is exerted and the object exerting the force. Draw your force vectors with the correct relative lengths to show the relative magnitudes of the forces on block B.

Rubric:

3 points: Completely correct free body diagram with no extraneous forces; forces have qualitatively correct relative magnitudes (or may have equal magnitudes or close to equal magnitudes for F_{ab} and F_{cb}). Forces begin on block B and point away from it.

2 points: Mostly correct free body diagram with up to one extraneous force OR one missing force OR incorrect magnitudes of forces (i.e., $F_{ab}>F_{cb}$)

1 point: Mostly incorrect free body diagram with one or two correct forces.

0 points: Completely incorrect or no attempt.

b. Identify all the Newton's 3rd law force pairs acting on block B (in the free body diagram you drew). Explain your reasoning for why you chose the pairs you did.

Rubric:

3 points: Completely correct answer Lists all the force pairs correctly and notes that the forces in a 3rd law pair are equal in magnitude and opposite in direction and that they act on different objects.

2 points: Only lists some of the force pairs (at least 2 pairs) correctly and notes correct reasoning. No incorrect pairs listed.

1 point: Incorrect, but thoughtful, attempt. May have one or two correct pairs listed, but also lists incorrect pairs (i.e., pairs the normal force from the table on block B with the weight of block B). May have no correct pairs but still a thoughtful attempt and still notes that a 3rd law pair is equal in magnitude and opposite in direction.

0 points: Completely wrong with no explanation or no attempt.

c. Do all the blocks experience the same net force? Rank the net force on each of the blocks and on the system as a whole, from largest to smallest. If any blocks experience the same net force, say so explicitly. Explain your reasoning.

Rubric:

3 points: Completely correct with correct ranking and explanation. $F_{system}>F_B>F_A>F_C$. *Ranking may leave out the net force on the whole system, but ranking of blocks is correct and explanation is entirely correct. The blocks move together so they have the same acceleration. According to Newton's 2nd law, because each block and the entire system have different masses, they will experience different net forces. Explanation specifically discusses blocks having same acceleration and different masses, so net force on each must be different.*

2 points: Mostly correct with partially correct or incomplete explanation. I.e., correct ranking but does not include the whole system in the ranking. Explanation may be incomplete, but at least partially correct. Ranking is correct but explanation is not entirely complete—i.e., mentions Newton's 2nd law in explanation but does not explicitly note that blocks all have the same acceleration.

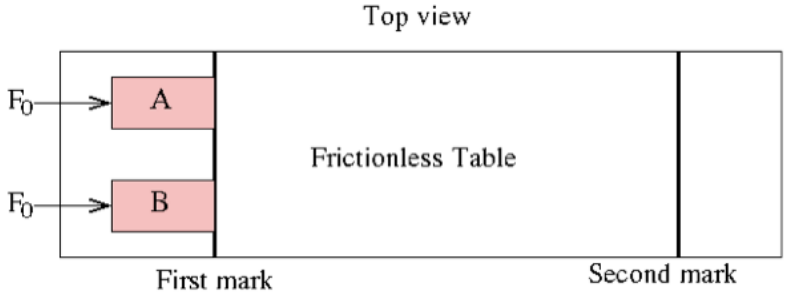
1 point: Incorrect but thoughtful attempt. I.e., partially correct ranking (only mixing up 2 forces) with an incorrect or partial explanation or an incorrect ranking with a thoughtful explanation.

0 points: Completely wrong with no explanation or no attempt.

Exam 3

FCI Category: Dynamics 2 (Newton's Laws and Impulse)

Two carts, A and B, are initially at rest on a frictionless, horizontal table. A constant force of magnitude F_0 is exerted on each cart as it travels from the first mark on the table to the second, after which each cart glides freely. The mass of cart A is less than that of cart B.



a. Is the magnitude of the acceleration of cart A greater than, less than, or equal to the magnitude of the acceleration of cart B while the carts are between the two marks? Explain your reasoning.

Rubric:

3 points: Completely correct with correct explanation. Acceleration will not be equal for the carts ($a_A > a_B$)—the carts both experience the same net force, but since their masses are different, their accelerations will be different. The least massive cart will have the greater acceleration. Since question specifies same net force, explanation does not need to explicitly refer to the carts experiencing the same force if instead it refers to Newton's 2nd law.

2 points: Mostly correct answer—correct answer with partially correct or incomplete explanation. I.e., explanation states that different masses mean different accelerations, with no explicit mention of the forces being the same or Newton's 2nd law.

1 point: Incorrect answer but a thoughtful attempt at explanation. I.e., the acceleration is the same because the forces on the carts are the same (no consideration of mass) OR correct answer with no explanation.

0 points: Completely wrong with no explanation or no attempt.

b. Is the kinetic energy of cart A greater than, less than, or equal to the kinetic energy of cart B after the carts have passed the second mark? Explain your reasoning.

Rubric:

3 points: Completely correct with completely correct explanation. The carts will have the same kinetic energy—both carts receive the same force over the same displacement, so the work done on the carts by the force is the same. According to the work-energy theorem, work is equal to the change in

kinetic energy and since both carts start from rest and have the same amount of work done on them by the applied force, they will have the same kinetic energy at the second mark. Explanation must explicitly discuss both the force and the displacement (W = Fd) and the work-energy theorem to show that the kinetic energies are equal.

2 points: Correct answer with partially correct or incomplete explanation. I.e., the carts get the same amount of kinetic energy because the work done is the same for both, with no mention of force and displacement or the kinetic energy is the same because the force is the same, with no mention of work, etc.

1 point: Incorrect answer but with a thoughtful explanation (i.e., $KE_A > KE_B$ because cart A has a higher speed or $KE_B > KE_A$ because cart B has more mass, etc.) OR correct answer with no explanation.

0 points: Wrong with no explanation or no attempt.

c. Is the magnitude of the momentum of cart A greater than, less than, or equal to the magnitude of the momentum of cart B after the carts have passed the second mark? Explain your reasoning.

Rubric:

3 points: Completely correct answer with correct explanation. The momentum of cart A is less than that of cart B. Both carts experience the same applied force, but since cart B is more massive, it will have a smaller acceleration and take a longer time to reach the second mark. Since cart B will experience the force for a longer time, it will receive a greater impulse. According to the impulse-momentum theorem, impulse is equal to the change in momentum and since both carts begin at rest, the cart that receives the larger impulse will have the larger momentum at the second mark. Explanation explicitly refers to the force and time (or impulse) and that impulse (or force times time) is equal to the change in momentum.

2 points: Correct answer with partially correct or incomplete explanation. I.e., Cart B has more momentum because it has a larger mass and takes a longer time, but with no mention of force or impulse.

1 point: Incorrect answer but thoughtful attempt at explanation (i.e., the have the same momentum because while one has a larger velocity, the other has a larger mass or they have the same momentum because they get the same applied force) OR correct answer with no explanation.

0 points: Completely wrong with no explanation or no attempt.

Appendix B

Collected Tutorials and Coding Scheme

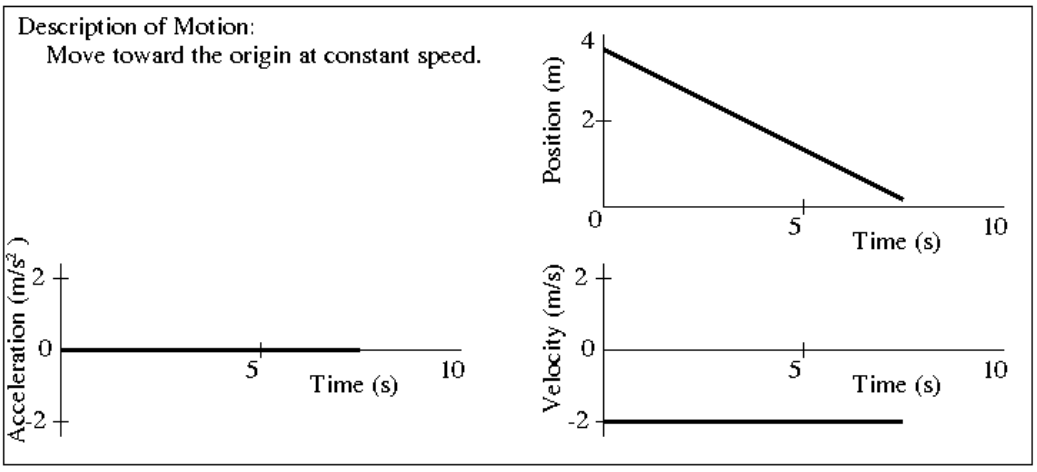
Only parts F and I of this tutorial are coded according to the instructional strategies. Part F is checked for how well students integrate ideas and part I for how well they apply their reasoning.

Tutorial: Representations of Motion

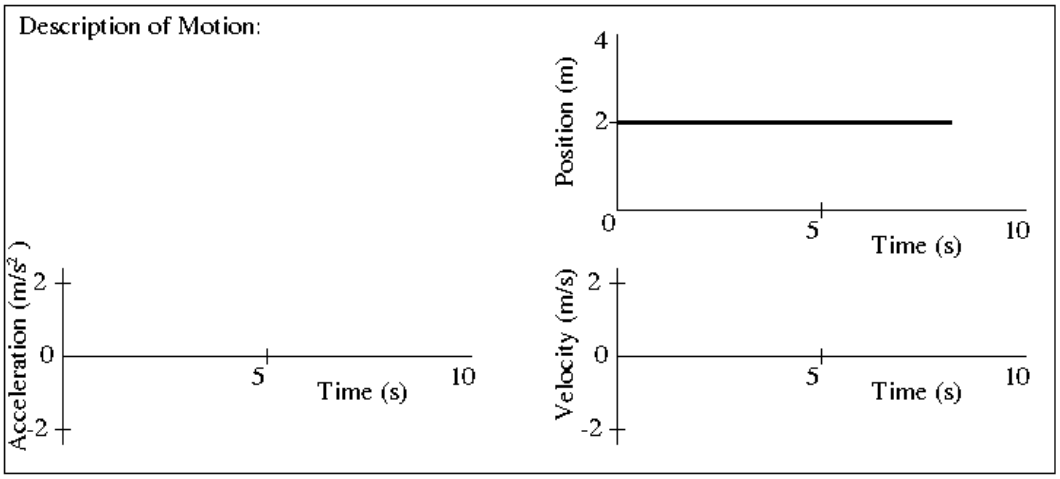
Instructions: In each of the following problems, you will be given one of the following descriptions of a motion:

- a written description, or
- an x vs. t, v vs. t, or a vs. t graph.

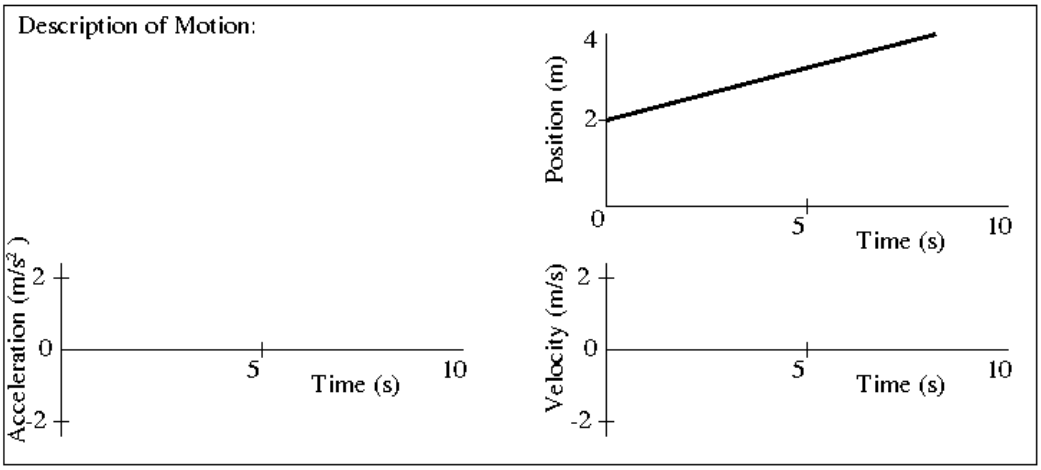
Fill in the other descriptions using the information given. In addition, answer the questions posed after each set of motion problems.
Example:



A.

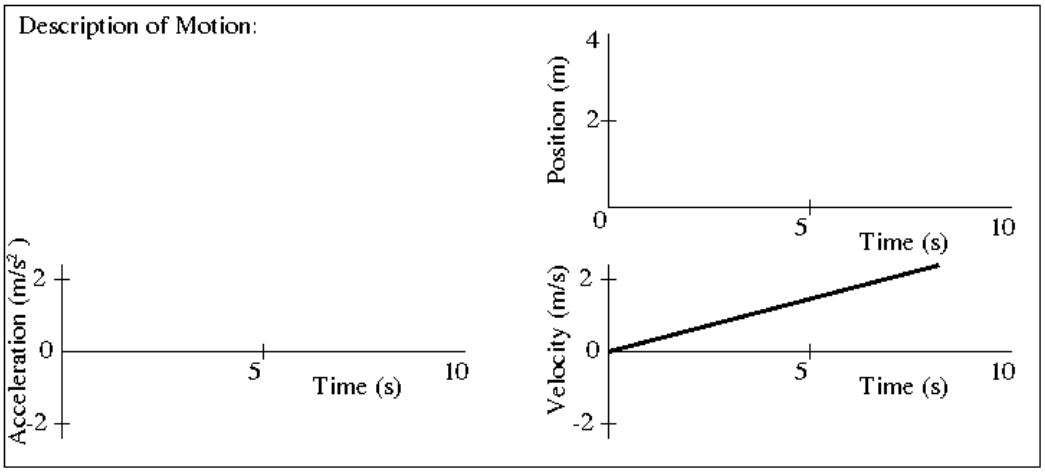


B.

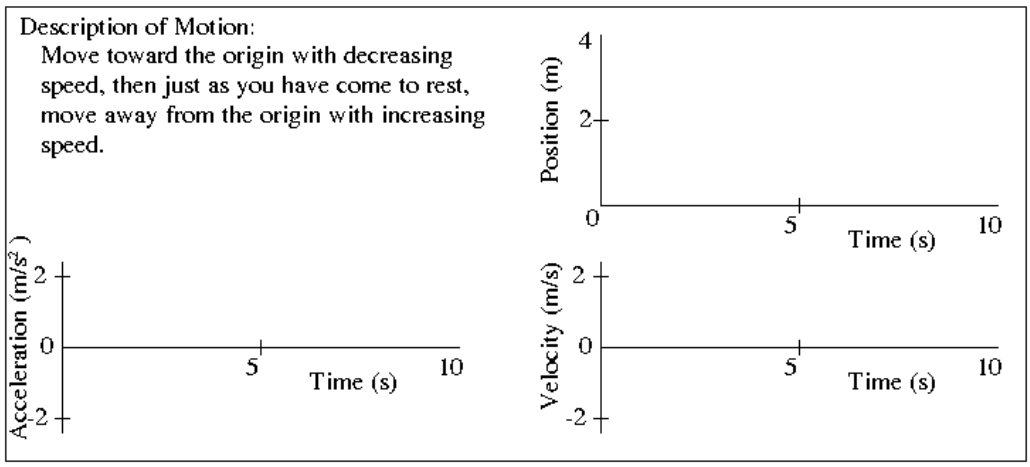


C. How are the motions in parts A and B similar? How are they different? How are the graphs similar? How are they different?

D.



E.



F. How do the acceleration graphs for D and E compare? Is it possible to have: a positive acceleration and slow down? a negative acceleration and speed up?

Integrate Ideas:

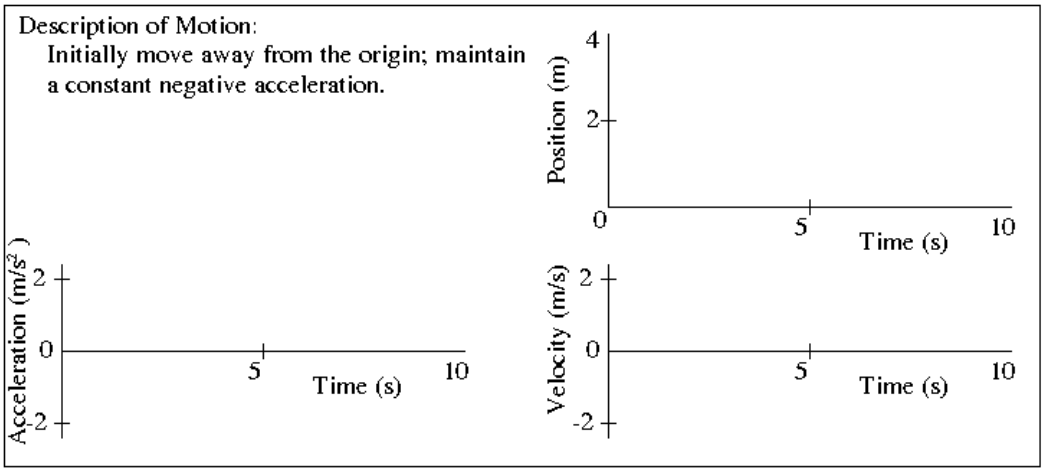
Ideas are sign of velocity, sign of acceleration, and whether speeding up or slowing down.

+2: Both ideas are integrated into an understanding of speeding up and slowing down.

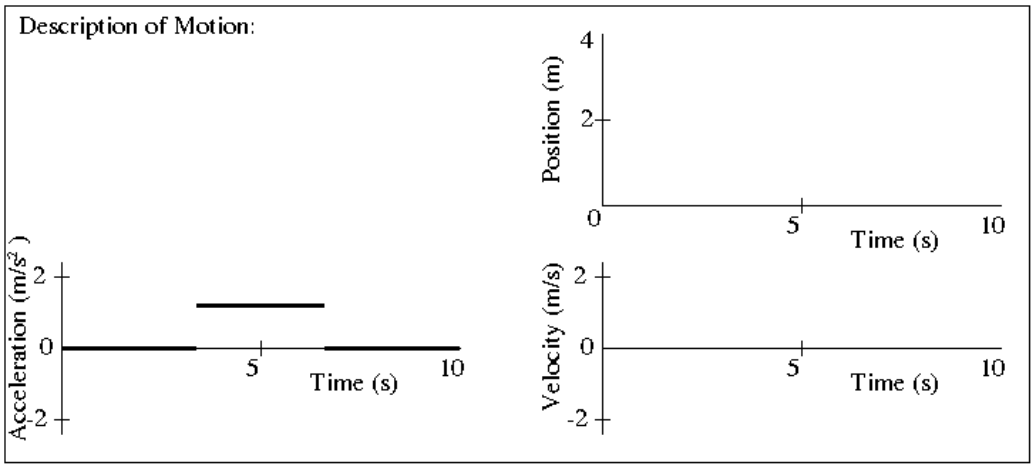
+1: Only one idea is connected with speeding up or slowing down (either sign of velocity OR sign of acceleration)

+0: No integration

G.



H.



I. The term decelerate is often used to indicate that an object is slowing down. Does this term indicate the sign of the acceleration?

Apply Reasoning:

+3: Correct and complete answer. The term decelerate does not indicate the sign of acceleration. Instead, it indicates whether the object is speeding up or slowing down—the relationship between the sign of the velocity and the sign of the acceleration.

+2: Correct answer with incomplete or incorrect reasoning.

+1: Incorrect answer with thoughtful explanation or correct answer with no explanation

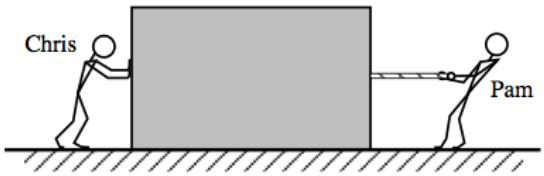
+0: Wrong or no attempt

Only parts I. E and II. A are coded. I. E is coded according to how well students justify their reasoning and II. A is coded according to how well students apply their reasoning.

Tutorial—Forces

I. Identifying Forces

Two people are attempting to move a large block. The block, however, does not move. Christ is pushing on the block. Pam is pulling on a rope attached to the block.



A. Draw a large dot in the space below to represent the block. Draw vectors with their "tails" on the dot to show the forces exerted on the block. Label each vector and write a brief description of that force next to the vector.

In Newtonian physics, all forces are considered as arising from an interaction between two objects. Forces are specified by identifying the object on which the force is exerted and the object that is exerting the force. For example, in the situation above, a gravitational force is exerted on the block by the Earth.

B. Describe the remaining forces you have indicated above in a similar fashion.

The diagram you have drawn is called a free body diagram. A free body diagram should show only the forces exerted on the object or system of interest (in this case, forces exerted on the block). Check your free body diagram and, if necessary, modify it accordingly.

A proper free body diagram should not have anything on it except a representation of the object and the labeled forces exerted on that object. A free body diagram ***never*** includes (1) forces exerted by the object of interest on other objects or (2) sketches of other objects that exert forces on the object of interest.

C. All forces arise from interactions between objects, but the interactions can take different forms.

Which of the forces exerted on the block require direct contact between the block and the object exerting the force?

Which of the forces exerted on the block do not arise from direct contact between the block and the object exerting the force?

We will call forces that depend on contact between two objects contact forces. We will call forces that do not arise from contact between two objects non-contact forces.

D. There are many different types of forces, including friction, tension, magnetic forces, normal forces, and the gravitational force. Categorize these forces according to whether they are contact or non-contact forces.

Contact forces Non-contact forces

E. Consider the following discussion between two students.
Student 1:
"I think the free body diagram for the block should have a force by Chris, a force by the rope, and a force by Pam."
Student 2:
"I don't think the diagram should show a force by Pam. People can't exert forces on blocks without touching them."

With which student, if either, do you agree? Explain your reasoning.
Justify Reasoning:
+3: Response is correct and includes correct and complete reasoning. (Student 2 is correct. Pam does not touch the block and cannot exert a non-contact force on it. The rope exerts a force on the block.)
+2: Response includes an answer and reasoning that logically matches the answer, but it is not necessarily correct.
+1: Response includes an answer and no or very minimal reasoning. Answer is not necessarily correct.
+0: No answer or reasoning.

It is often useful to label forces in a way that makes clear (1) the type of force, (2) the object on which the force is exerted, and (3) the object exerting the force. For example, the gravitational force on the block by the Earth might be labeled $F_{g,\,BE}$.

F. Label each of the forces on your free body diagram in part A in the manner described above.

Do not proceed until instructed to do so.

II. Drawing free-body diagrams

A. Sketch a free body diagram for a book at rest on a level table. Remember, a proper free body diagram should not have anything on it except a representation of the book and the forces exerted on the book.

Make sure the label for each force indicates the type of force, the object on which the force is exerted, and the object exerting the force.

1. What evidence do you have for the existence of each of the force on your diagram?

2. What observation can you make that allows you to determine the relative magnitudes of the forces acting on the book?

How did you show the relative magnitudes of the forces on your diagram?

Apply Reasoning.

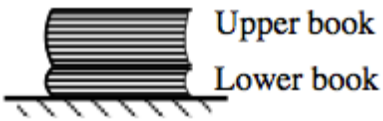
+3: Completely correct FBD and all three questions correct. The FBD has two labeled forces of equal magnitudes, beginning on the object and pointing away (normal force up and gravitational force down). The book is in contact with the table, so the table exerts a normal force on the book. The book is on the Earth and is subject to the gravitational interaction with the Earth, so there is a gravitational force acting on it. The book is not moving, so the net force on it is zero. By Newton's 2nd law, zero net force means that the two forces have the same magnitude in opposite directions, so the force arrows are drawn to be the same size.

+2: Correct FBD and 2 of 3 questions is correct.

+1: Incorrect or mostly incorrect. May have correct FBD and one question correct or questions are correct with incorrect FBD.

+0: Completely wrong or no attempt. May have FBD but does no answer questions.

B. A second book of greater mass is placed on top of the first.



Sketch a free body diagram for each of the books in the space below. Label all the forces as in part A.

Upper Book Lower Book

Specify which of the forces are contact forces and which are non-contact.

1. Examine all the forces on the two free body diagrams you just drew. Explain why a force that appears on one diagram should not appear on the other diagram.

2. What type of force does the upper book exert on the lower book (frictional, gravitational, something else)?

Why would it be incorrect to say that the weight of the upper book acts on the lower book?

3. What observation can you make that allows you to determine the relative magnitudes of the forces on the upper book?

4. Are there any forces acting on the lower book that have the same magnitude as a force acting on the upper book? Explain.

C. Compare the free body diagram for the lower book to the free body diagram for the same book in part A (i.e., before the upper book was added).

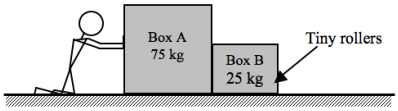
Which of the forces changed when the upper book was added and which remained the same?

Only parts B and C of this tutorial are coded. Part B is coded according to how well students justified their reasoning and part C is coded according to how well students integrated ideas.

Newton's 3rd Law

Boxes on Rollers

Consider the following situation: A student pushes two boxes, one in front of the other, as shown. Box A has a mass of 75 kg and box B has a mass of 25 kg. Fortunately for the student, the boxes are mounted on tiny rollers and slide with negligible friction. The student exerts a 200 N horizontal force on Box A.



A. Here are some questions about the blocks' accelerations.
   1. Without doing any calculations, state whether the acceleration of block A is greater than, less than, or equal to that of block B. How do you know?

   2. Using any method you want, find the acceleration of the blocks. (Hint: It is possible to do this quickly.)

   3. There are two approaches to multi-body problems: (i) Lumping together the various objects and thinking of them as a single big mass, or (ii) thinking separately about each object. Which approach did you use to find the acceleration?

B. Box B contains kitchen stuff, including some poorly packed glassware that might break if the force pushing on the side of the box approaches 200 N. Recall that the student pushes on Box A with a force of 200 N. Is that force "transmitted" to box B? In other words, is the glassware in the box in danger of breaking? Don't do any calculations—answer intuitively and explain your thinking.

Justify Reasoning:

+3: Correct answer with complete and logical reasoning that matches. The entire force is not transmitted to box B. Box B moves with the same acceleration as box A, but its mass is less, so the net force on box B must be less as well.

+2: Response includes an answer and reasoning that matches logically, but the answer is not necessarily correct.

+1: Response includes an answer and no or very minimal reasoning. Answer may or may not be correct.

+0: No attempt.

C. Now we'll figure out whether the 200 N force is felt by box B:
   1. Draw separate free body diagrams for box A and for box B:

   2. Assume that the 200N force is "transmitted" to box B:
      i. If it is true that $F_{A \text{ on } B} = 200N$, then how strong is $F_{B \text{ on } A}$?

      ii. If $F_{A \text{ on } B} = 200$ N, then what is the net force on box A?

      iii. Based on the previous calculations, should we accept or reject the assumption that the 200 N force the student exerts on box A gets "transmitted" to box B?

Integrate Ideas:
Ideas are Newton's 2nd law and Newton's 3rd law.
+2: Student shows understanding of both Newton's 2nd and 3rd laws (i. -200N, ii. net force is zero) and puts that together to reject the assumption that the 200 N force on box A gets transmitted to box B. (Student may also calculate the net force on either box A or box B—or both—as well as or instead of rejecting the assumption).
+1: Shows understanding of 2nd and 3rd laws (-200 N and zero net force), but fails to put them together and reject the assumption.
+0: Only understands one of Newton's laws and does not reject the assumption.

D. In this particular problem, did it help your reasoning to draw a free body diagram for both boxes? Explain.

E. Find a way to calculate $F_{A \text{ on } B}$ exactly, and do it.

F. Try to find an intuitive way of understanding why $F_{A \text{ on } B}$ is less than 200 N. Explain your reasoning here.

G. Reviewing their work on the two-box problem, a group of students is discussing whether to label the force on block B as $F_{A \text{ on } B}$ or $F_{\text{student on } B}$. One of the students in the group states,

"The rule says that you're supposed to label it $F_{A \text{ on } B}$. But this is one of those rules that is an arbitrary choice, like the rule that red means stop and green means go. Breaking this rule wouldn't actually mislead you when you're solving a problem."
Do you agree that the rule is an arbitrary choice, or do you think there is some kind of deeper reason behind it? Explain.

Only parts II. C, IV. D, and VI. D are coded in this tutorial. Part II. C is coded according to how well students integrate ideas, part IV. D is coded according to how well students integrate ideas, and part VI. D is coded according to how well students apply their reasoning.

Momentum and Conservation of Momentum—"Oomph"

This activity introduces momentum conservation. Equally important, using momentum as an example, this activity explores the extent to which formulas relate to common sense.

I. What's your view?

A. (Work individually) Which of the following best expresses your view about the relationship between physics formulas and common sense? (You can choose more than one.)

- Many physics concepts make a lot of sense and connect to everyday experience, but formulas are more of a problem solving tool than a sense-making tool.
- It really depends on the formula. Some of them make sense, but you shouldn't expect them to make sense as a general rule.
- In general, physics formulas express some kind of common sense ideas.

B. Compare your answers with the rest of your group. If there was disagreement, have a debate—not to convince each other, but to understand each others' views. If someone makes a good point that disagrees with what you initially thought, summarize that point here.

II. Figuring out the formula for oomph

An important physical quantity corresponds to the intuitive idea of oomph. The more oomph something has, the harder it is to stop and the more ability it has to knock other things over. Let's figure out the formula for oomph. If you already know the formula from a previous class, please 'play along' and don't give it away. This tutorial is structured so that you should learn something even if you already know the formula.

A. (Work together) A small pebble and a larger rock are thrown at the same speed.
   1. Which one has more oomph? Why?
   2. The rock is twice as massive as the pebble. *Intuitively*, how does the rock's oomph compare to the pebble's oomph? Is it twice as big? Half as big? Three times as big?

B. (Work together) Picture two identical bowling balls, one of which is rolling faster than the other.
   1. Which ball, the faster or slower one, has more oomph? Why?
   2. The faster ball is exactly 7 times as fast as the slower one. *Intuitively*, how does the faster ball's oomph compare to the slower ball's oomph?

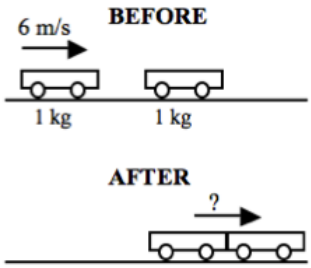
C. (Work together) The physics concept corresponding to oomph is *momentum*. Building on your above answers, figure out a formula for momentum in terms of mass and velocity. Explain how the formula expresses your intuitions from parts A and B above. For historical reasons, physicists use the letter *p* for momentum.

Integrate Ideas:
Ideas are mass, velocity, and momentum.
+2: Completely integrate ideas of mass and velocity into an equation for momentum.
+1: Only gets one idea—understands that momentum depends on both mass and velocity, but gets wrong equation/relationship
+0: Blank or completely did not get it

III. Intuitions about Collisions

Above, your intuitions about oomph led to a formula for momentum. Now let's see if your intuitions about collisions lead to similar progress.

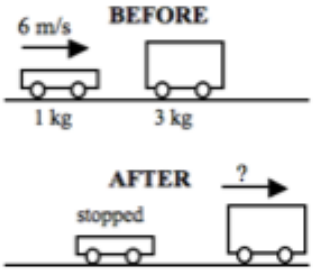
A. (Work together) A 1 kg cart, rolling with negligible friction at 6 m/s, collides with and sticks to an identical cart. So, after colliding, the carts roll together as a single unit.



1. Using your intuitions, guess the post-collision speed of the two carts. Briefly explain your reasoning.

2. According to the intuitive guess you just made, is the overall momentum of the two cart system after the collision greater than, less than, or equal to the overall momentum before the collision? Work this out using the momentum formula you figured out above and plugging in the relevant numbers.

B. (Work together) In a similar experiment, the 1 kg cart collides with a 3 kg cart but doesn't stick to it. Instead, the 3 kg cart gets knocked forward by the 1 kg cart, which comes to rest after the collision.

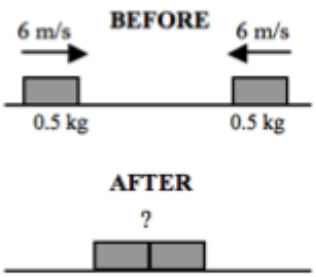


1. Again, guess the post-collision speed of the 3 kg cart.

2. According to the intuitive guess you just made, is the overall momentum of the two-cart system after the collision greater than, less than, or equal to the overall momentum before the collision?

C. (Work together) Based on your work above, state a general rule about how the total momentum of a system changes during a collision.

D. Let's look at one more collision. Two identical blocks, both of mass 0.5 kg and covered with Velcro, slide toward each other at equal speeds of 6 m/s. The blocks stick together.



1. Intuitively, after the collision, how fast do the blocks move and in what direction?

2. In the cart collisions from part A and B above, momentum was conserved; it was the same before and after the collision. Because conserved quantities are useful in problem solving, it would be nice if we could define momentum in such a way that it is always conserved in collisions (between objects that are free to move). Is there some way to modify or clarify the momentum formula you figured out earlier so that momentum is conserved in the head-on collision between the two blocks? (Hint: Maybe oomph 'cares' about direction.)

IV. Deriving momentum conservation

Let's play the implications game, applying Newton's 2nd and 3rd laws to a collision between objects 1 and 2 and see where that leads us.

As we saw with the truck and car scenario, Newton's 3rd law says that objects 1 and 2 exert equally strong forces on each other, in opposite directions.

$F_{2 \text{ on } 1} = -F_{1 \text{ on } 2}$

A. (Work together) Suppose that, during the collision, the forces exerted by the objects on each other are the net forces felt by each object. Use Newton's 2nd law ($F_{net} = ma$) to rewrite the formula above in terms of the mass and accelerations of the objects during the collision (m_1, a_1, m_2, a_2).

B. (Work together) Now use the basic definition of acceleration to rewrite that equation in terms of the masses (m_1 and m_2), the changes in velocity of each object during the collision (Δv_1 and Δv_2) and the time interval over which the collision occurs (Δt).

C. (Work together) Now multiply through by Δt. Does the result look familiar?

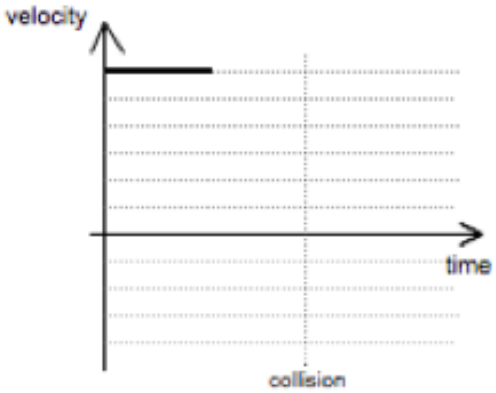
D. (Work together) Based on the derivation you just did, state a general rule about when momentum is conserved and when it isn't.

Integrate ideas:
Ideas are Newton's 2nd and 3rd laws and conservation of momentum.
+2: Completely integrated Newton's laws into a statement of conservation of momentum.
+1: Only partially integrated ideas—worked through Newton's laws but did not get a statement of conservation of momentum
+0: Did not integrate ideas

Hint: In parts A through C, what assumption or assumptions did you make besides Newton's laws?

V. Applying momentum conservation

(Work together) A cart of mass 1 kg, rolling along a level track with negligible friction, collides with a stationary cart of mass 2 kg. Due to Velcro, the carts stick together and move as a single unit after the collision. We've sketched the first few moments of the 1 kg cart's velocity vs. time. Complete the graph, being as exact as possible.



VI. Conservation of momentum

Conservation of momentum is a fundamental physical law. Among other things, it says that when two objects collide, the total momentum of the system immediately after the collision equals the total momentum of the system immediately before the collision:

Conservation of Momentum: $m_1\vec{v}_{1,before} + m_2\vec{v}_{2,before} = m_1\vec{v}_{1,after} + m_2\vec{v}_{2,after}$

Since $\vec{p} = m\vec{v}$ and since velocity "cares" about direction, so does momentum. So, a negative momentum (oomph) can partially or fully cancel a positive momentum, as the Velcro blocks demonstrated.

(Work together) Let's practice using momentum conservation. On a safety test course, a 100 kg car heading north at 5 m/s collides head-on with an 800 kg car heading south at 4 m/s. At these low speeds, the new high tech bumpers prevent the cars from crumpling; instead they bounce off each other. After the bounce, the 1000 kg car is heading south at 1 m/s. We're going to ask for the post collision speed and direction of motion of the car.

A. What's a good first step in this problem, one that will help you avoid mistakes? After coming to consensus, do that step.
B. Without doing calculations, "guess" the final direction of the lighter car. Briefly explain your reasoning.
C. Now calculate the lighter car's speed and direction of motion after the collision. Make sure everyone in the group is comfortable with this.
D. If you didn't already do so, check for consistency between your intuition in question B and your formal answer in question C.

Apply Reasoning:

+3: Completely correct and shows all work. v = 3.5 m/s north. Student uses the conservation of momentum equation correctly, with correct signs for velocities before and after and shows all work.

+2: Mostly correct. v =3.5 m/s north. Uses conservation of momentum but does not explicitly show all work.

+1: Incorrect but thoughtful. Uses conservation of momentum, but applies it incorrectly or inconsistently (may not keep track of signs in the equation, etc.) OR correct answer with no work shown.

+0: Completely wrong or no attempt

Appendix C

Colorado Learning Attitudes About Science Survey Statements

Introduction

Here are a number of statements that may or may not describe your beliefs about learning physics. You are asked to rate each statement by circling a number between 1 and 5 where the numbers mean the following:

1. Strongly Disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly Agree

Choose one of the above five choices that best expresses your feeling about the statement. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, choose 3.

Survey

1. A significant problem in learning physics is being able to memorize all the information I need to know.

2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.

3. I think about the physics I experience in everyday life.

4. It is useful for me to do lots and lots of problems when learning physics.

5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

6. Knowledge in physics consists of many disconnected topics.

7. As physicists learn more, most ideas we use today are likely to be proven wrong.

8. When I solve a physics problem, I locate an equation that uses the variables given in the problem and plug in the values.

9. I find that reading the text in detail is a good way for me to learn physics.

10. There is usually only one correct approach to solving a physics problem.
11. I am not satisfied until I understand why something works the way it does.

12. I cannot learn physics if the teacher does not explain things well in class.

13. I do not expect physics equations to help my understanding of the ideas; they are just for doing calculations.

14. I study physics to learn knowledge that will be useful in my life outside of school.

15. If I get stuck on a physics problem my first try, I usually try to figure out a different way that works.

16. Nearly everyone is capable of understanding physics if they work at it.

17. Understanding physics basically means being able to recall something you've read or been shown.

18. There could be two different correct values to a physics problem if I use two different approaches.

19. To understand physics I discuss it with friends and other students.

20. I do not spend more than five minutes stuck on a physics problem before giving up or seeking help from someone else.

21. If I don't remember a particular equation eeded to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.

23. In doing a physics problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem.

24. In physics, it is important for me to make sense out of formulas before I can use them correctly.

25. I enjoy solving physics problems.

26. In physics, mathematical formulas express meaningful relationships among measurable quantities.

27. It is important for the government to approve new scientific ideas before they can be widely accepted.

28. Learning physics changes my ideas about how the world works.
29. To learn physics, I only need to memorize solutions to sample problems.

30. Reasoning skills used to understand physics can be helpful to me in my everyday life.

31. We use this statement to discard the survey of people who are not reading the questions. Please select agree-option 4 (not strongly agree) for this question to preserve your answers.

32. Spending a lot of time understanding where formulas come from is a waste of time.

33. I find carefully analyzing only a few problems in detail is a good way for me to learn physics.

34. I can usually figure out a way to solve physics problems.

35. The subject of physics has little relation to what I experience in the real world.

36. There are times I solve a physics problem more than one way to help my understanding.

37. To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.

38. It is possible to explain physics ideas without mathematical formulas.

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

41. It is possible for physicists to carefully perform the same experiment and get two very different results that are both correct.

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Appendix D

Interview Questions and Coding Scheme for Student Views of Physics

Interview questions about students' views of physics. Each question and follow-up questions is followed by a coding rubric and an example of a student response that fit that code.

1. What do you think about physics as a subject (not the course)?
   +2: Student indicates that they like physics very much, find it extremely interesting, are very enthusiastic about learning physics.
   "I feel like it is a very fundamental subject in that a lot of other subjects, you couldn't understand other subjects without knowing physics first. For example, the way systems work in your body or certain mechanical things in the real world or in your body or anywhere you need to know physics. It is the basic fundamental workings of the world."
   +1: Student indicates that they like physics a little bit or see that it is relevant, but are not enthusiastic about learning physics.
   It is interesting, but I don't see where I'm going to have to use it in my field. It's cool to know, like, projectile motion and all that stuff, but I really don't care for it."
   +0: Student indicates that they do not like physics at all, does not see the relevance of physics, and is not at all enthusiastic about learning it.
   "I think of physics as largely irrelevant to anything I'm studying because I'm a bio lab person. But it is a requirement so I have to take it."

   a. Do you find physics interesting?
      +2: Students find physics very interesting.
      "Yes. It's just the world around us. It is as much about the feet on the ground as it is the stars in the sky, so it's just really cool."
      +1: Students find physics only a little interesting.
      "Vaguely, like I said, not my favorite. I like, when I'm outside and I see something happen, if I know why it happens. Like, if I see a ball thrown, that kind of thing. Kind of learn the concepts behind why it has motion. I like that."
      +0: Students do not find physics interesting at all.
      "No, and the reason I don't find it interesting is that I find it very difficult and it takes a lot of time and effort to actually understand a concept. I get lost really fast in physics and I get resistant to the learning and I want to just stop."

   b. Do you feel like learning physics will be (is) useful to you outside of class?
      +2: Students feel that physics will be/is very useful outside of class.
      "Yeah, I do. I am pre-med so I feel like my path and my future career it will help me to understand how certain things work, how certain chemical things interact and all that. It just gives you a basis, a foundation towards the understanding of medicine."
      +1: Students feel that physics will be/is only a little useful outside of class.

"My major is athletic training and so with something like biomechanics. I can see the usefulness there, but when you take a general physics course as a whole, I guess I don't see the use of applying the things that we're learning."
+0: Students do not feel that physics will be/is useful outside of class at all.
"I have yet to find a time, but maybe someday. I can't think of any instances to pre-med."

c. Do you feel like physics knowledge is useful in the wider world?
+2: Students feel that physics is very useful in the wider world (and not just in STEM based fields; and can give at least one example).
"Yeah, it explains the things that happen around us. It is everywhere I go. Like when you fly a plane. All of the different factors that go into a plane being able to go off the ground. Air resistance, gravity, things like that."
+1: Students feel that physics is only a little useful in the wider world (mainly in STEM fields, but not for everybody or useful in the general sense but can't think of any examples).
"Yeah, like in the army or what not. Intercepting missiles, trying to see if the plane is going to go off the boat in time, with the landing, stuff like that. In terms of a career, yes., if you work in the sort of career that has to do with physics or hard science, then yes. But outside of that, if you're just in a group of friends talking, I don't think physics is on your mind. It isn't going to govern how you live your life."
+0: Students do not feel that physics is useful in the wider world.
No students felt that physics was not useful at all.

2. Describe your approach to studying physics/doing physics homework.
This question was not coded.

a. How important is memorizing information to your studying?
+2: Memorizing is not important to studying (instead focus on understanding concepts, talks about concepts, logical thinking, etc.).
"I think memorizing is not really the way to go and isn't that important. I think it's more important to understand how things work and be able to, like, given a situation apply what you know. So I think, like, maybe a very basic memorization of a formula or something, but it's really important to understand the concepts and be able to reason through it, I think."
+1: Memorizing is only a little bit important (also talks about understanding concepts); or not important but with no other explanation; or prefers to memorize but thinks it won't be useful here.
"I think knowing the concepts is ideal, but I think some of the concepts are over my head, so if I can remember the basics of the concepts and memorize those things like what they're about or just memorize how to do something."
+0: Memorizing is very important or the primary way to learn physics (no mention or focus on understanding concepts).

"Very important. I always have to memorize the definitions of the words in order to start working out the equation."

b. How much time do you spend thinking about concepts when you are solving a problem?

+2: Students spend a lot of time thinking about concepts (at least half of problem solving time; it depends on complexity, but a lot).

"Quite a bit. That's usually the main part. Like, conceptually, I needed to make sure that he numbers make sense. And even after, so then I'll put the numbers to it or write out my answer and then I'll stop and think about it again and ask if that makes sense. Does it make sense that this value is larger or smaller or whatever."

+1: Students spend only a little bit of time thinking about concepts (instead focus on finding the right equation or a similar example, etc.); not much time in terms of assignment/problem; less than half.

"Usually you don't have to spend that much time thinking about it because it's like, in the back of your mind. It'll like, click when you're doing it. And if you don't, like, remember how to do the problem, maybe you'd have to go back through your notes or something."

+0: Students spend no or very little time thinking about concepts (instead focus only or mainly on finding the right formula, copying a similar example, etc.)

"When solving a problem, not a whole lot. Because with physics it's like, here's an equation and you have these variables, so fill them. You're not thinking about he's going this way so your acceleration is going to be negative or in the positive direction. You don't think about that. It's just plug and chug, really."

c. Do you feel like you can use the concepts you are learning now later in the semester? (for the first interview)

d. Do you feel like you are still using concepts from earlier in the semester or does it all seem new? (for later interviews)

+2: Students feel like they can use many ideas from earlier in the course (and give an example)

"I think it all kind of builds on each other. If you're studying pressure, I guess the concepts of kinematics might not overlap, but the straightforward motion in air, like projectile motion, might not overlap, but learning, I guess, the fundamental of how the forces relate to acceleration that helps you later on. So, I guess the relationship between different vectors or different forces I guess that helps you later on."

+1: Students feel like they can use one or two ideas from earlier, but not very many, and things mostly seem new.

"I feel like we're using some points from earlier on, but I feel like it's a lot of new stuff too."

+0: Students feel like they won't use any earlier ideas and everything will be a new idea

No students' responses were coded in this way.

3. How confident are you in your ability to learn physics?

+2: Students are very confident in their abilities

"I'm pretty confident. I think, like, there's always an answer. It's just a matter of how long it's going to take me to find it."

+1: Students are somewhat confident in their abilities

"I've never been very confident in anything I'm learning, but I feel a little bit better with this course. People around me say that I know what I'm talking about, but I don't feel confident."

+0: Students are not confident in their abilities

"Right now, not that confident. I took physic sin high school and did really well, but now, the way we're approaching it with graphs and trying to think about it and not doing it the math way, it's really hard for me to understand and I can't just think about, oh well, if you have two balls this is what it's going to be like. Like, I just can't think of it realistically happening."

a. What do you do if you can't figure out a problem/question or get stuck?

+2: Willing to put in a lot of effort to figure it out—try it again, think about the concepts, check notes, look at other sources (internet, books, etc.), ask another student, a tutor, or professor. Will definitely try to figure it out themselves, either through their notes or other sources, before asking someone else.

"I think of all the things that I already know that I can use. What do I know is true and if that doesn't work, then I'll write out all the information in the problem, all my variables, and if I still don't see all the things come together I'll go through the book and notes and try. And if I still don't get it I'll go to the internet or the help center or something."

+1: Willing to put in some effort—maybe 2-3 of these things, but not all. Usually goes straight to talking to someone else instead of trying it themselves first.

"Look it up, google it, ask a friend. Look through my book first and see if I can find something that points in the right direction. But even if I find something that looks right, I'll ask somebody else."

+0: Not willing to put in any or minimal effort—only one of the things, generally straight to tutors or professors.

"I'll have to ask someone, like the professor. If she isn't there, then maybe go on blackboard or see if another student knows or ask a friend if they know how to figure it out."

b. What do you do if you get an unexpected result on a problem or if your answer doesn't make sense

+2: Willing to put in lots of effort—think about whether it really is realistic or unexpected, re-check problem, try again on their own, go to notes or other sources, ask another student, tutor, professor (Doesn't have to do all of these, but does most of them, in this order)

"If it doesn't make sense, I usually, especially with the questions, it's been, like, what is this variable's answer or something. Like, if it is supposed to equal zero and it equals 5, most of the time I'll try to work the problem out a gain, not looking at the other one, and then, if that doesn't work I seek out other people, how are you doing it, what am I doing wrong. There was a problem the other day in class that I had everything all worked out, but I missed gravity on my calculation, so everything was all wrong because of gravity."

+1: Willing to put in some effort—think about whether realistic or unexpected, re-check problem, maybe ask somebody, but gives up fairly easily.

"Check my math or I'll try and re-do it again. Or, I'll ask someone else what they got and if it's in the ballpark, then…"

+0: Not willing to put in any or minimal effort—goes straight to asking someone else without trying themselves first.

"I understand that I'm not going to know everything right away and I sometimes get frustrated, but I go get help. There's a specific tutor who explains things really good so I like her."