

GAINS FOUND IN MARYLAND PHYSICS EXPECTATION SURVEY
FOR INTRODUCTORY COLLEGE PHYSICS

by

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ITHACA COLLEGE

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ABSTRACT

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We have conducted investigations to determine how students learn physics in a calculus-based introductory physics course and how to improve upon our teaching methods to give students a better understanding of the course material and how to approach scientific learning. The course demographic has a mix of science majors with the majority looking to pursue some form of physics degree. Using two well-verified, standardized tests, one measuring conceptual understanding and the other measuring students' approach to learning physics, we monitored and evaluated student learning in a performance-based physics classroom. Our investigations conducted over the past four years show that our students demonstrate a higher level of conceptual knowledge and show characteristics of professional physicists after taking our calculus-based Newtonian Mechanics course.

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Chapter 1

Introduction

Many students, especially at the college level, enter introductory physics courses with preconceptions that have been strongly developed and reinforced throughout their lives. Unfortunately their preconceptions are often incorrect. Ironically, many studies indicate that, despite these initial misconceptions, students leave their introductory college physics courses with no gain in their understanding of basic physics and no change in their attitudes towards learning and doing physics [5]. However, over the last decade, physics education researchers have used several survey instruments to measure these attitudes and beliefs to distinguish how students change over the course of a semester.

We used two distinctive surveys to assess student learning in a calculus-based introductory physics course. First, the Force Concept Inventory (FCI), which is an exam designed to evaluate students comprehension and understanding of central concepts in Newtonian mechanics that is one of the most widely used diagnostic exam in physics education. Second, the Maryland Physics Expectations Survey (MPEX), is used to study the attitudes, beliefs, and expectations of introductory physics students. We report the preliminary results of a four-year study of overall learning gains found

on both the MPEX and FCI. We discuss the difference in our teaching styles and give reasons as to why our students come away with the ability to think more like physicists in their understanding of successful strategies for learning physics, and with clear gains in conceptual understanding of physics.

The surveys used for this research are summarized in Appendices A and B.

1.1 Exploring student understanding, attitudes and beliefs about physics

The Maryland Physics Expectations Survey (MPEX) was developed by the Maryland Physics Education Research Group to study the attitudes, beliefs, and expectations of students in an introductory calculus-based physics course [12]. There are favorable and unfavorable responses to the survey questions that can help administrators determine if a student is looking for the quick fix of memorization or is committed to learning physics. The information that students take away from a lecture or class period is related to their expectations of the course and what they believe the professor expects of them. Students who try and memorize the equations presented in an introductory physics class and assign each equation to a particular problem don't develop effective problem solving techniques or conceptual understanding [10]. We examined how problem solving is approached in this course and what is stressed to the students.

Introductory problem solving in physics is viewed by students as knowing what equation, or string of equations, to use in order to determine the value of one or more unknown variables [4]. This method is entirely formula centered and ignores the central concepts that contribute to the understanding of Newtonian physics. Students entering a physics classroom come with a well established system of commonsense

beliefs and life experiences of how the physical world works. Some of these experiences reinforce false or incomplete understanding of physics. Since the central concept of Newtonian mechanics is *force*, states Hestens, Wells, and Swackhamer (2001), we have utilized an instrument to probe student beliefs on this matter and how these beliefs compare with many dimensions of the Newtonian concept [4]. The instrument used at Ithaca College is called the Force Concept Inventory (FCI) and has been used in a wide range of high schools and universities.

While some student misconceptions are easily corrected others go against their intuition and are harder to fix. There are stages in which students just want to be told the “right” answers, and a stage in which students take charge of building their own understanding [13]. Our goal is to get students to reach this latter stage and think like physicists, as critical and analytical thinkers.

1.2 Why we are conducting this study

We have set out to gain a better understanding of how students learn physics and respond to physics teaching. Overall we would like to see if there is a correlation between how a student performs on the MPEX-pre or post test and how they perform as a student in terms of GPA. Can scores on surveys such as MPEX, or FCI, or both predict how a student will perform in the classroom? We want to see if performance on either of the preliminary surveys will show elevated exam, homework, or other course work scores.

We have improved upon the methods in teaching so as to identify the key places where students diverge in their learning. This is not a new concept; scientific research has been trying its best to answer the questions raised in this paper for years [8] [1] [2] [11]. It's been found that at the end of a student's conventional study they have little

structure to their knowledge [7]. Student understanding consists of random facts and equations that they identify with a structural feature described in a problem (inclined plane, rope, spring, etc.) and shows little conceptual understanding [5]. Our objective is to help students construct a deeper understanding of the basic concepts of physics. The ability to be an effective instructor requires more than dedication and subject knowledge, it requires technical knowledge about how students learn. [5]

Chapter 2

Background Information

In this section, we discuss the previous work in science education research as it pertains to the FCI and MPEX instruments. In our study each test was always administered at the beginning and end of the first term of introductory calculus-based physics which is a course on Newtonian mechanics.

Research at other institutions has shown that the traditional lecture style class has left students confused about the basic concepts of mechanics. [2] Many institutions throughout the United States have started to adjust their teaching styles by changing from a lecture to a student centered, active learning approach.

2.1 Past Findings

Redish (1998) stated that the crucial element in understanding student learning is that students are not “blank slates.” Their experience of the world leads them to develop many preconceptions that are not always consistent with what they are being taught in their physics courses. It has been demonstrated that if this element, when student preconceptions that are also misconceptions, are taken into account, it is

possible to provide activities that create a new structure of thinking in order to develop a functional understanding of the basic concepts. Redish wanted his students to develop a robust knowledge structure with a complex of mutually supportive skills and attitudes, not just a patchwork of ideas. He wanted them to develop a strong understanding of what science is and how to do it. His goal was to have his students develop the skills and confidence necessary to do science independently. [13]

The Maryland Physics Expectation (MPEX) survey was developed to study the attitudes, beliefs, and expectations of students that have an effect on how they learn in an introductory calculus-based physics course. [12] The survey is discussed at length in section 2.3. Once Redish constructed and administered his survey he found that the number of responses identified as favorable declined after the completion of one semester of instruction at every school studied. A significant part of the deterioration was claimed to be because the students felt that they did not put in as much effort as they had expected to put in at the beginning of the semester [13]. What was more surprising was that many of the schools also showed deteriorations on the cognitive dimension of the survey. Half deteriorated on the independence dimension, which tests student beliefs about learning physics and whether it means receiving information or involves a more active approach to increase ones understanding. Two thirds decreased on the coherence dimension, which looks at student beliefs about the structure of physics knowledge to test if physics is seen as a collection of isolated pieces or as a single coherent system. Half deteriorated on the math link, where the role of mathematics in learning physics was tested. And all decreased on the reality link, which relates the connection between physics and the experiences outside of the classroom. [13]

From this Redish was able to determine that what is being taught in introductory classes does not improve student attitudes and beliefs about physics and some

of what is taught is counterproductive. “In order for professors to learn how to help their introductory students transform their approach towards learning physics, careful observations are required to explicate the elements of an appropriate set of expectations” [13]. Redish presented his survey in order to explore the issues he raised and to expand our understanding of what is really going on in the classroom.

Another element that we need to evaluate is what students are learning in their introductory courses, not only how their expectations have changed. Evaluating what concepts a student has entering into a course and what they take away with them in the end needs a different survey instrument. The FCI enables professors to determine what type of questions students are misguided about and allows them to tailor the course accordingly to those particular students. Giving this survey at the beginning and the end of the course allows professors to track their progress of different teaching methods. The FCI is discussed at length in section 2.3.

An example of the FCI’s use was demonstrated by Professor Alan Van Heuvelen of New Mexico State University when he visited Arizona State University to implement a new teaching style. He took over two consecutive fall terms of a physics course intended for students who have not taken high school physics and prepare them for calculus-based physics. The pretest scores on the FCI for this group were not much better than that of the pretest high school level scores. Due to these pretest scores and lower math background it was expected that the students would perform at the lowest level. However, the post test scores were clearly superior. Once Heuvelen left and the course was taught by Arizona’s own professor it was noted that improvements in the laboratory portion of the course were the deciding factor that seemed to reflect the improved Inventory post test scores. [4]

2.2 Teacher Expectations at Ithaca College

The goal for our calculus based physics course is to teach students to solve problems, both qualitative and quantitative. But to learn physics you must do physics. Doing physics is thinking about and applying concepts, problem solving skills, and mathematical tools. We want to refine their skills in development and their communication on problem solutions. The problems the students are asked to solve are conceptual, experimental, and mathematical all of which are inter-related and help them better understand physics.

The course objectives set out at the beginning of class are: To acquaint students with calculus-based Newtonian Mechanics, help understand the difference between an exercise and a problem, help become a better problem solver, introduce estimating to obtain meaningful results, and help students learn how to effectively communicate scientific information.

Our research questions are:

- How does the initial performance of a student on either the FCI or the MPEX correlate with their success in the class?
- How does the initial state of the class, measured by pre-test scores, compare to other institutions and what is Ithaca College doing differently?
- How does the performance and expectations of the students change after completing the course and how does that compare to other institutions?

2.3 History and Detailed Description of the MPEX and FCI

Evaluating how a student expects to learn or the preconceptions they enter into a classroom with are difficult to measure. Thankfully there are surveys that already exist to use at our disposal. For this project the MPEX and FCI were chosen to evaluate introductory calculus based physics students at Ithaca College, their history is discussed below.

2.3.1 MPEX

Redish set out to answer three questions Q1:*How does the initial state of students in university physics differ from the views of experts?* Where the initial state of a student refers to a students' understanding of what science is about and how it is done and their expectations as to what goes on in a science course. Redish looks at the preconceptions a student enters with and their expectations of the class prior to any instruction. Redish defined "expert" as the response that was given by a majority of experienced physics instructors who have a high concern for educational issues and a high sensitivity to students. He was able to conjecture that experts, when asked what answers they would want their students to give, would respond consistently.

Q2:*To what extent does the initial state of a class vary from institution to institution?* Redish reported on results collected from 1500 students in introductory calculus-based physics at six colleges and universities: two-year college, state school, liberal arts schools and large universities. Each used a variety of approaches. The initial state of students deviated significantly from that of the expert calibration group. The overall responses ranged from 50 – 60% favorable, see Table 1 for favorable vs. unfavorable responses. The three large state institutions where student attitudes were

measured via MPEX were very similar to each other. The attitudes of beginning students at the select liberal arts institutions were consistently more favorable. And the two year college being tested showed consistently less favorable results compared to the state institutions [13].

Q3:*How are the expectations of a class changed as the result of one semester of instruction in various learning environments?* He constructed a survey to administer at the beginning and end of a course to probe student expectations about successful strategies for learning physics and how those expectations either improve or deteriorate as a result of one semester on instruction. [13]

Students are asked to agree or disagree on a five point scale with 34 statements about how they see physics and how they think they work in their physics courses [12] with a focus on six structures:

- independence
- coherence
- concepts
- their link between physics and their real world
- their understanding of the role of math in physics
- the kind of effort they expect to make to do well in the course

The survey was calibrated using five groups. When the survey was distributed to professional physicists across all areas of physics they answered the same (better than 80%). The favorable vs. unfavorable response for each category is described in Table 1. The groups expected to be of higher caliber were in strong agreement on almost all the responses. The majority of their responses were defined as favorable. [13] Redish hypothesizes that students who become effective scientists already have or will develop these attitudes and therefore part of an introductory physics course should be to help students begin to develop these attitudes. All students were asked to complete the

Table 1. Dimensions of student expectations adapted from Redish's paper [13]

	Favorable	Unfavorable	MPEX Items
independence	takes responsibility for constructing own understanding	takes what is given by authorities (teacher, test) without evaluation	1, 8, 13, 14, 17, 27
coherence	believes physics needs to be considered as a connected, consistent framework	believes physics can be treated as unrelated facts or "pieces"	12, 15, 16, 21, 29
concepts	stresses understanding of the underlying ideas and concepts	focuses on memorizing and using formulas	4, 19, 26, 27, 32
reality link	believes ideas learned in physics are relevant and useful in a wide variety of real contexts	believes ideas learned in physics has little relation to experiences outside the classroom	10, 18, 22, 25
math link	considers mathematics as a convenient way of representing physical phenomena	views the physics and the math as independent with little relationship between them	2, 6, 8, 16, 20
effort	makes the effort to use information available and tries to make sense of it	does not attempt to use available information effectively	3, 6, 7, 24, 31

survey during the first week of the term and at the end of the term [12].

2.3.2 FCI

The Force Concept Inventory was designed to improve on a previous Mechanics Diagnostic test. It assesses a student's overall grasp of the Newtonian concept of force. Though percentage scores on the Inventory and Diagnostic are similar, the Inventory has the advantage of supplying a more systematic and complete profile of a student's various misconceptions. [4] About half the questions in the Inventory are the same as in the Diagnostic. Therefore, the Inventory score would be an upper bound on a

student's understanding on Newtonian concepts.

When applied to first-year graduate students beginning graduate mechanics at Arizona State University the results were congruent with expectations. Interviews were conducted after the exam to help understand the reasoning behind incorrect answers. Only two of the students exhibited a perfect understanding of all physical concepts on the Inventory. One missed several questions because of a severe English deficiency. As the class progressed these two students were the best in the class, with near perfect scores on every test and problem assignment. Of the class there were three students who did poorly on the Inventory showing a deficient understanding of buoyancy and who also didn't clearly understand Newton's Third Law as detected by missed questions. The student with the most severe misconception failed graduate mechanics miserably where the other two managed to barely complete their first year of graduate school on probation. [4]

The Inventory was revised after initial testing, the authors had to discard questions from their original version that were misread more often than not. The data collected contains an abundance of information. Key concepts assessed are whether professors successfully address Kinematics, Newton's First, Second, and Third Law, Superposition Principle, and Kinds of Force. [4]

The Force Concept Inventory can be used for both instructional and research purposes. It can be used as a diagnostic tool to identify and classify misconceptions, for evaluating instruction when looking at the pre and post test gains, and as a placement exam to help determine whether a student's understanding of introductory physics is sufficient for a more advanced course. [4]

Chapter 3

Experimental Design

3.1 The Classroom

The class that we are evaluating here at Ithaca College is a calculus-based physics course, Principles of Physics I: Newtonian Mechanics. This is the first college science course many of the students take at Ithaca College. We have seen positive changes in student performance on MPEX in the past four years (Fig.4.7) largely due to the implementation of a new performance-based-physics teaching method, facilitated by a specially designed classroom based on scale-up/studio physics. The style of the class has changed from a lecture-only to a student-centered, interactive learning environment. Context-rich problem solving and peer instruction (Sec. 3.4) is at the heart of the class unlike calculus-based introductory physics courses at many other institutions [6]. Our performance-based physics classroom is composed of eleven round tables each able to hold nine students. There are three groups of three students at any one table. Each group is supplied with their own laptop computer and groups may interact in an intimate setting. This classroom is used for many other introductory and advanced physics classes, see Table 3.1. The classroom is able to hold up to 99

Table 3.1 List of courses and their enrollments

Course	Enrollment
Introduction to Physics I	68
Introduction to Physics II	72
Principles of Physics: Newtonian Mechanics	28-33
Principles of Physics: Electricity and Magnetism	28-33
Physics of Sound	60
Solar System Astronomy	78
Stars, Galaxies, and the Universe	80
Astrophysics	30
Selected Topics in Advanced Physics	7-12

students at one time and can also be split into 1/3 and 2/3 of its size to accommodate for smaller classes. Class size for the calculus based course is about thirty students each year.

Unlike in lecture halls where students are able to discuss physics primarily with the neighbors to the right or left, our students sitting at round tables now have a larger group discussion atmosphere during the entire class period. Group membership is determined from the top 1/3, middle 1/3, and bottom 1/3 as assessed by FCI scores. Initially, no group has a woman or ethnic minority by themselves. Groups are changed every three to four weeks after each exam, using the to-date scores to pick the top 1/3, middle 1/3, and bottom 1/3 again. No student will be grouped with a former group member. The final groups of the semester are selected by the students.

The class is anchored with Personal Response System questions that probe students conceptual understanding of class material and supply the professor with immediate feedback as to what topics students are struggling, or not struggling with. The instructor highlights throughout the course questions that are to be seen as ‘exercises’, these questions should merit a quick response, where students should easily see the pathway to the solution. Responses that take more time are identified as ‘problems’.

The students are encouraged to discuss problems that have a split answer and try to arrive at the correct solution through their own thought process and sharing with others [6]. We assume that students are more likely to think through the reasoning of another student's response. When a student gives an answer s/he may believe s/he is correct, the student sitting across the table may also think s/he is correct with a different answer, and the discussion begins as to why each student thinks he or she is correct. At first students want to be told the "right" answer and resist open discussion, but as the class becomes more comfortable with each other, and with professor encouragement, conversation starts to flow. The students are now thinking through the concepts as opposed to being told the correct answer. This should help turn students away from trying to memorize the "right" answer that they can reproduce on an exam and get them to think of physics as a problem solving process.

3.2 Majors enrolled in the class

The class is offered once a year in the fall semester and has about thirty students, one third to one half of whom are physics majors. We are interested in what major each student is enrolled in because we want to study how they perform and how they improve based on their chosen profession. Are the math students more likely to think like the professional physicists and be more willing to figure problems out? What about other science majors such as Chemistry? How do they score on the MPEX and FCI? Do their preconceptions based on their chosen field sway their thinking and how they adapt to the new method of teaching? The other category on the demographic chart holds majors such as business, psychology, computer science and so on. We are not very interested in these majors on an individual level because there are not enough students with those majors to make up a significant statistical sample. We

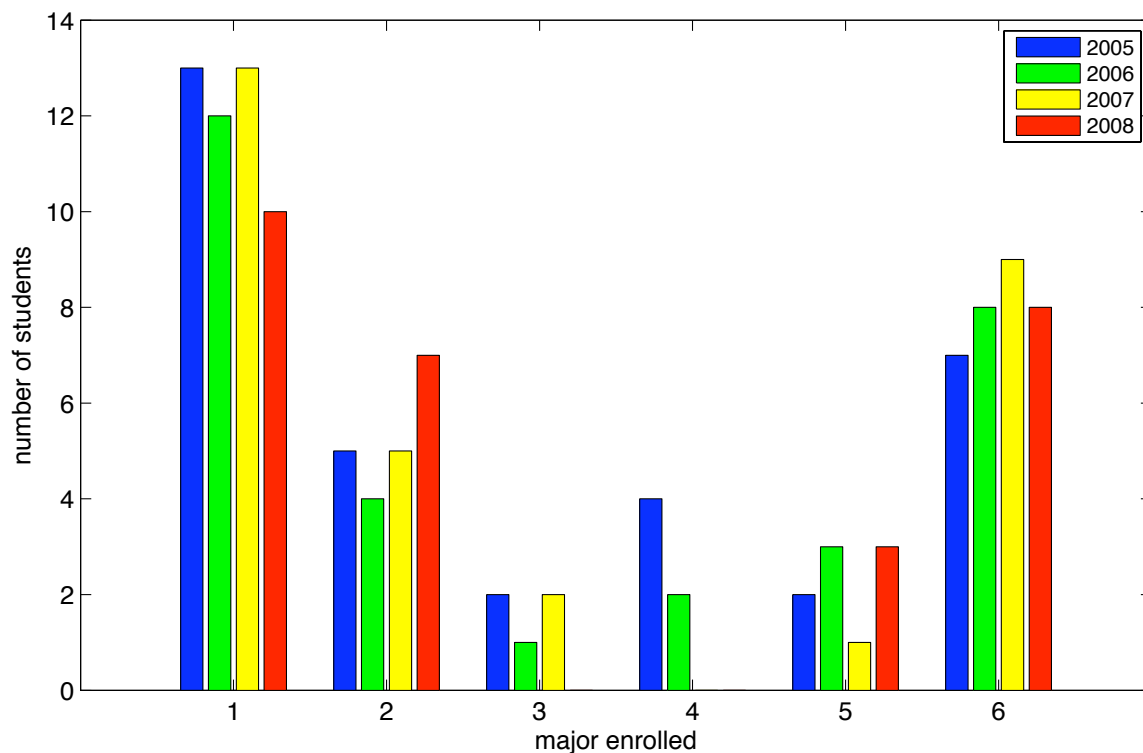


Figure 3.1 The number of students by major that enrolled in Principles of Physics: Newtonian Mechanics and are included in our study. 1 = physics BA, physics BS, math-physics, physics 3-2 engineering, and physics teaching, 2 = chemistry, 3 = biology, 4 = mathematics, 5 = biochemistry, 6 = other

will lump them together and see on the whole if there is any significant finding that we could compare to the science majors. See Fig. 3.1 for the demographic of each year of our study.

3.3 Number of years surveys have been administered

This study has been ongoing since 2005 fall semester. The implementation of the new approach and the new physics classroom has made a tremendous difference in the interaction between teacher and student.

The first day the students take both the MPEX and FCI. They are assured that their performance on the exam will not effect their grade in the class. Their scores are recorded in a spreadsheet and their progress is tracked throughout the course until the final day of class when the students take the same survey again as part of their final exam for points. They are not told that this survey would reappear when it was first administered. The professor is very careful not to teach to the test so the results are less biased. Each year of our study the course was taught by the same professor. Thus same teacher expectations are held and the same methods are used.

3.4 Context rich problem solving

Context-rich problem solving is a group activity that occurs once a week in our course. These problems are intended to be challenging and aim to help students learn how to solve “real-world” problems. Context-rich problems were developed by the University of Minnesota Department of Physics Education Research and Development Group [17] where they have cooperative, structured learning groups solve problems that meet a very specific criteria. Through years of research and careful observation of these learning groups, the University of Minnesota’s Department of Physics has seen that in order for their groups to function properly, the problems need several characteristics:

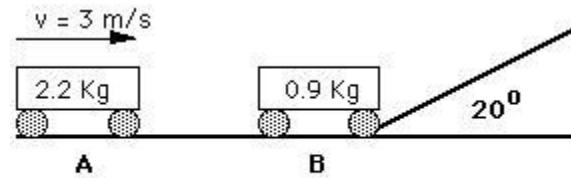


Figure 3.2 Adapted from the University of Minnesota Department of Physics website. [17]

- The problems should be challenging enough that a single student cannot solve them, but not so challenging that a group cannot solve it.
- The problems should be structured so that the groups must make decisions on how to proceed with the solution.
- The problems should be relevant to the lives of the students.
- The problems should not depend on students knowing a trick nor can they be mathematically tedious.

These context-rich problems are set up in such a way that traditional end-of-the-chapter textbook problems usually do not fit the mold. Below is an example that the UMN physics department uses to show the difference between traditional “problems” and context-rich problems. [17]

Cart A, which is moving with a constant velocity of 3 m/s, has an inelastic collision with cart B, which is initially at rest as shown in Figure 3.2. After the collision, the carts move together up an inclined plane. Neglecting friction, determine the vertical height h of the carts before they reverse direction. [17]

This example of a traditional textbook problem demonstrates many features that are not conducive to student interest and learning. It uses unreal objects that do not necessarily tie physics to the real world. The physics is also clearly spelled out in the description and therefore does not require further assumptions or decision making.

A picture is included which denies the student any flexibility or creative thinking in how the problem could be set up or approached. Finally, the variables are pre-defined for the students.

Here is an alternative example of how conceptual understanding can be assessed the by the context-rich method:

You are helping your friend prepare for her next skate board exhibition. For her program, she plans to take a running start and then jump onto her heavy duty 15-lb stationary skateboard. She and the skateboard will glide in a straight line along a short, level section of track, then up a sloped concrete wall. She wants to reach a height of at least 10 feet above where she started before she turns to come back down the slope. She has measured her maximum running speed to safely jump on the skateboard at 7 feet/second. She knows you have taken physics, so she wants you to determine if she can carry out her program as planned. She tells you that she weights 100lbs. [17]

Additional aspects that have been implemented into the calculus-based Newtonian physics class here at Ithaca College have been the clearly explained and well developed grading rubric for these problems, see Table 3.2, where all elements are weighted equally. Students would expect that their grade-performance on a problem would be determined entirely on their final answer. The context-rich problem solving emphasizes that the process in which you solve a physics problem is just as important, if not more, as the final answer. Another aspect that is just as important as the method used to reach a result is the ability to communicate those scientific results to others clearly and concisely and talk about science.

Table 3.2 Context-rich problem grading rubric as adapted from the Ithaca College PHYS-117 course website.

Quality	Poor	Fair	Excel.
Points	20	70	100
Id. Give Information, unknowns, and desired results			
Estimated Uncertainty			
Assumptions			
Schematic			
Free Body Diagram			
Organized Given Information			
Outlined Steps (before beginning analysis)			
Analysis (Calculations, graphs, or scaled diagrams)			
Explained math steps using English			
Left equations in variable form until the end			
Estimations			
Checked to see if result is reasonable			
Discussed the result in the context of the question			
Units			
Overall Organization			

Chapter 4

Data and Analysis

Since the Fall 2005 class we have had 121 students participate in this study; 89% of those students have taken both the pre and post-test surveys. All pre testing is denoted by a (+) and all post by (.) on Fig. 4.1, Fig. 4.2, Fig. 4.3, and Fig. 4.4. The scores, for both the pre and post, are plotted for each student (e.g. student 1,2,3..etc.) along with the best fit line to show the overall trend for Fig. 4.1 and Fig. 4.3. The mean score is plotted for Fig. 4.2 and Fig. 4.4 which has the graphs separated by class year. While the scores seem very scattered across a wide range there is a very distinct trend that follows. Each survey shows a clear gain in both the FCI and MPEX post scores. While there are few students that may have a small gain, no gain, or negative gain the trend of the overall group is an increase in score from pre to post. This is expected for the FCI, after students have taken the course we expect their conceptual understanding of Newtonian physics to have increased. The scores for the FCI are based on a correct or incorrect answer just like a normal exam. This is the case for all other institutions as well [4] [14].

There is also an increase in post scores for the MPEX, see Fig. 4.3. This means that after students take the calculus-based introductory physics course on Newtonian

Mechanics they think more like professional physicists. The scores on the MPEX are based on their answers as compared to how the professional physics community expects them to answer.

The information we get from the FCI pre and post-test scores help us analyze not only an individual student, but the class as a whole. We are able to monitor performance level and conceptual understanding throughout our study. As shown in Fig. 4.1 the student pre-test scores, while well distributed, are consistent across all four years (2005-2008) that the survey has been conducted. We use this survey tool to distinguish between class and it will help to show any anomalies that may arise. Such as an entering class with abnormally high pre-test scores showing the majority of the class has an elevated mastery of the material. This, however, is not the case Fig. 4.2 shows the breakdown of each class by year. These graphs (A-D) show a rough representation of the class performance by plotting the mean score for the pre-test in blue and the post-test mean plotted in red to show a pre/post-test distinction.

Each year we have a selection of incoming students that perform at the same level. Fig. 4.1 also shows the post-test scores for the FCI with its line fit, plotted in red. From this post-test information I can determine that the students, overall, receive higher scores after completion of the course in their conceptual knowledge of the course material taught over the semester. The line fit of the two pre and post-test scores clearly represents an equal scoring increase over the four years. This could be attributed to the course being taught by the same professor each year with the same learning objectives. It would be interesting to see how the post-data plot would change if a different professor were to teach the course or if we had an incoming class with extreme high/low scores. Would the ending post-test scores be the same showing a classes learning capacity? Or would the entire plot just be shifted up or down respectively. We get to see this data next Fall.

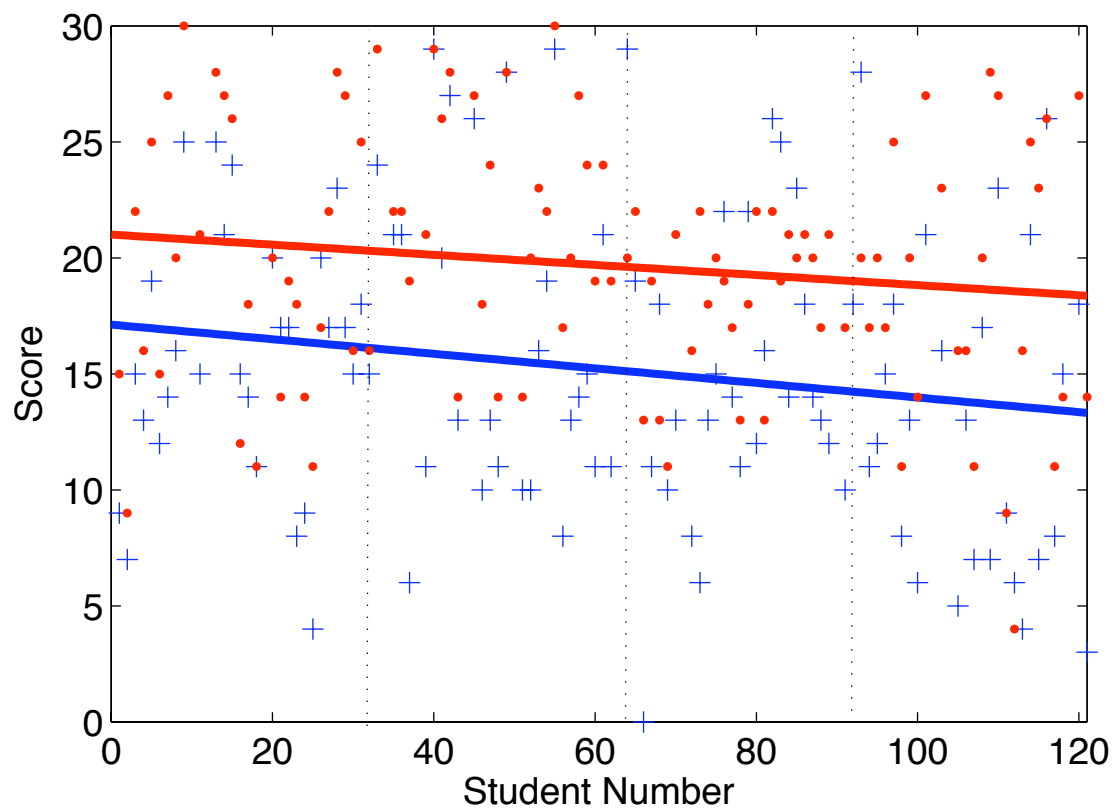


Figure 4.1 Student pre scores on the FCI (+) and the post scores (.) Plotted are the raw scores each student received for their pre and post-test. The FCI is scored out of 30. Over the four years the survey has been administered 121 students have participated, shown here chronologically. The vertical dashed lines show the breakup of the class year starting in the Fall of 2005. The solid lines represent the line fit for the pre-test (in blue), and the post test (in red).

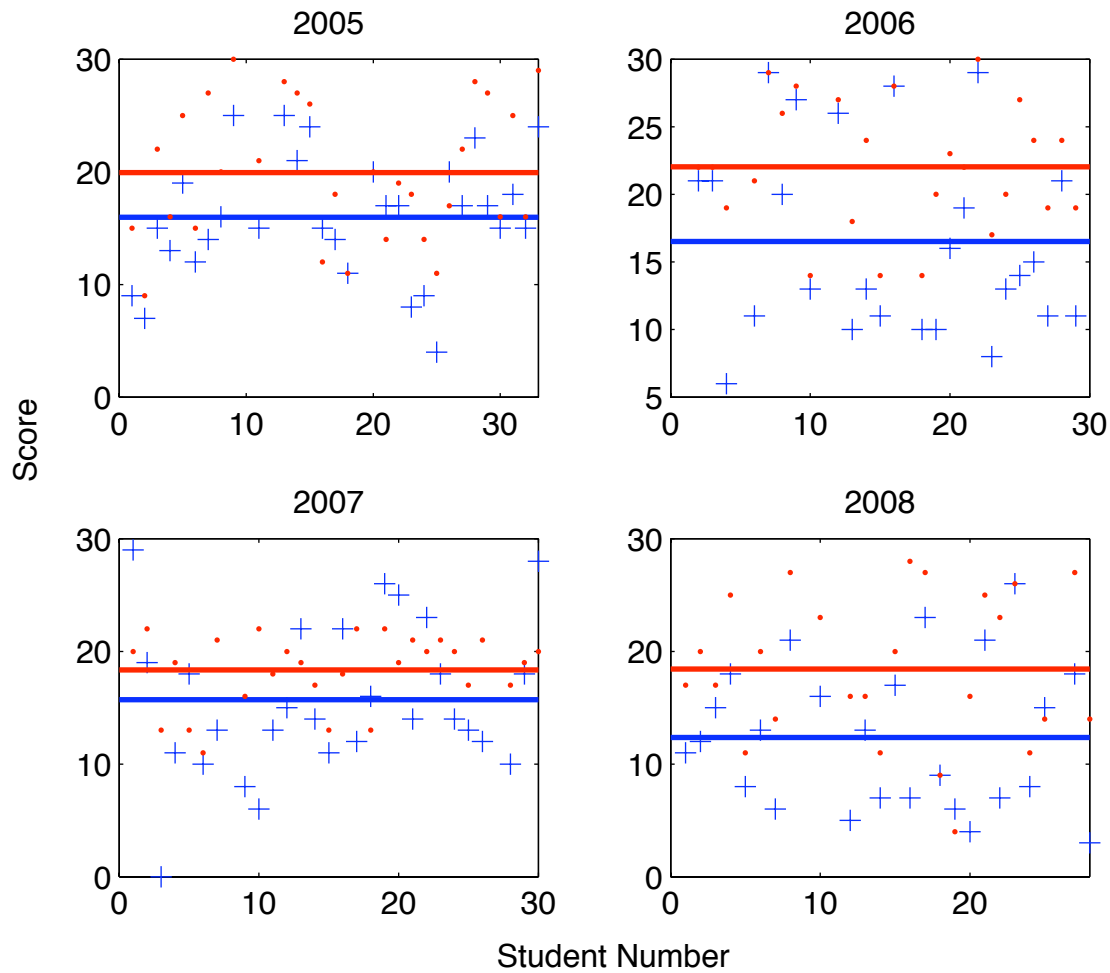


Figure 4.2 Student pre scores on the FCI (+) and the post scores (.) separated into the Fall 2005-2008 semesters. Each year shows an improvement in raw scores after completion of the course. The line fit for each of these plots is just a visual reference to show the difference between the pre and post scores. Since the student number was randomly assigned the slope of the fit line is arbitrary.

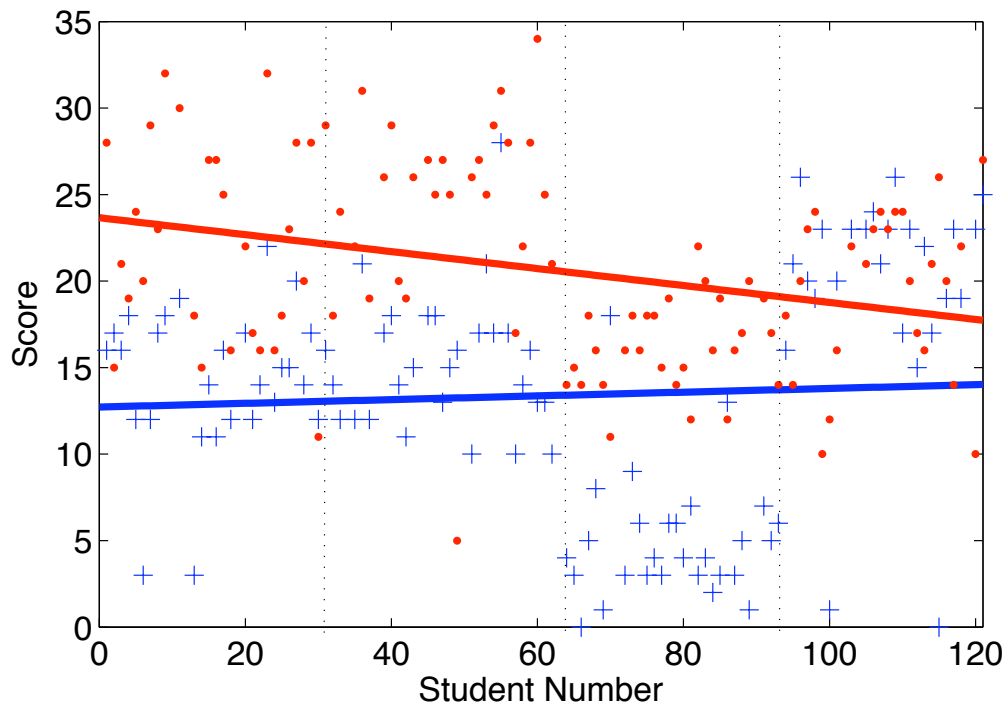


Figure 4.3 Student pre scores on the MPEX (+) and the post scores (.) The MPEX score is determined based on how many survey questions, out of 34, each student answers in congruence with professional physicists answers. Each student is randomly assigned the same student number as used for the FCI (see Fig. 4.1). The vertical dashed lines mark the change over to a new class year. The solid lines represent the line fit for the MPEX scores, pre-test = blue, post-test = red.

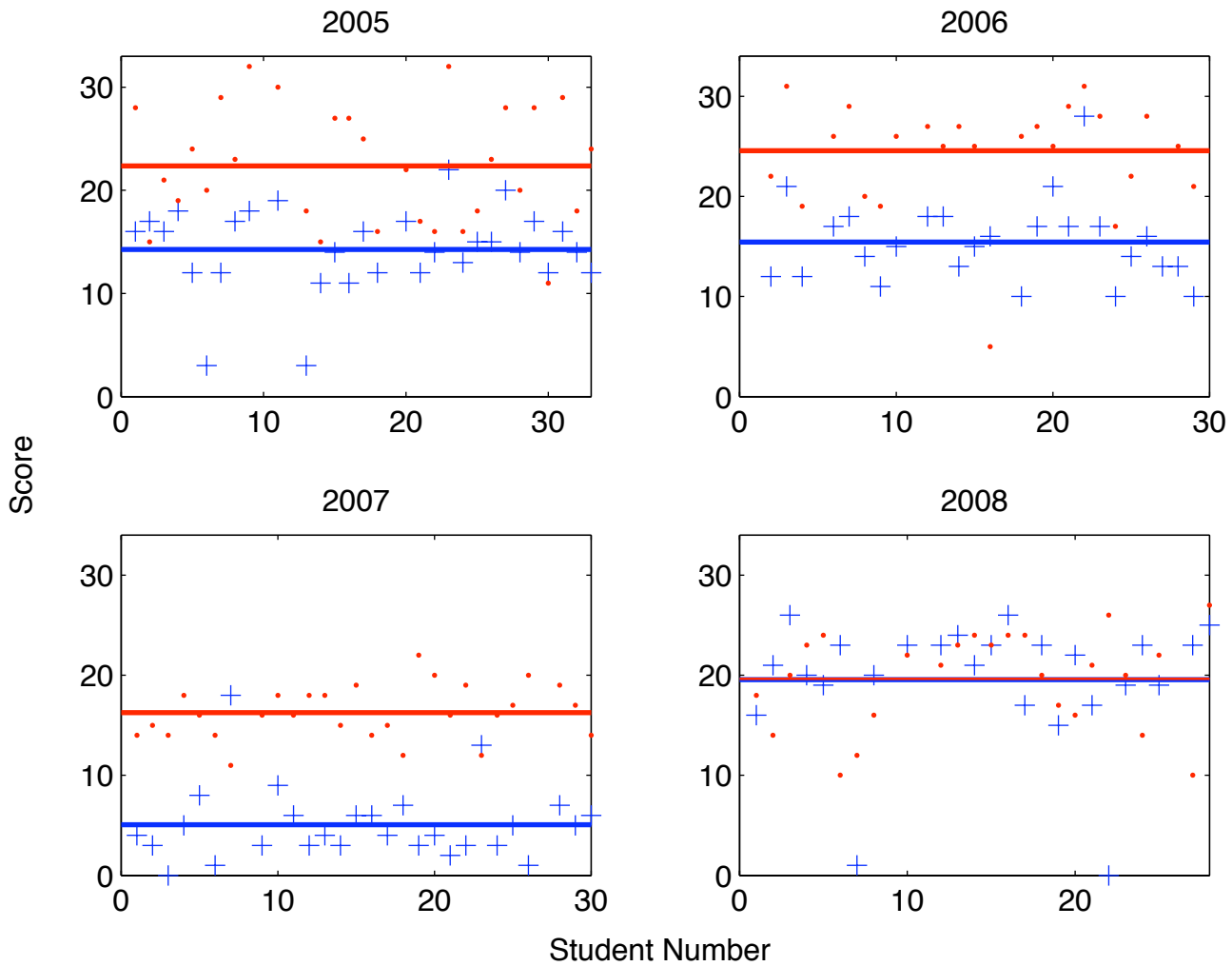


Figure 4.4 Student pre scores on the MPEX (+) and the post scores (.) for the Fall 2005-2008 semesters. The line fit for each of these plots (A-D) is a visual reference to show pre and post scores. Since the student number was randomly assigned and corresponds to their FCI scores as well, the slope of the line here is arbitrary.

One of our objectives is to analyze the MPEX data. Fig. 4.3 is a breakdown of how each student scored on their pre-test and post-test. As you can see, we can report an overall increase in final score on the MPEX. This is something not perviously recorded for this particular surveying tool [13] [7]. The first 60 students, from the Fall class of 2005 and 2006 separated by the vertical dashed line, are very similar to each other in how they responded to the MPEX on both the pre and post-test. The pre-test line fit is somewhat level for its representations of the students score on the pre-test overall, although there is clearly a group that is well below and above the median. The post-test scores show a decreasing trend as the years progress.

4.1 Statistical Significance

In this paper, our research questions involve surveying different groups of students at different times. In every group studied there are individual data that fluctuate and have no real significance to our analysis overall. In order to compare the groups — beginning and end of semester surveys, student groups between each year— we are comparing their averaged responses to understand whether any two data sets are significantly different.

In a large group of students assume that a percentage p_0 of responses to a question are favorable or correct and a percentage q_0 will be unfavorable or incorrect with $p_0 + q_0 = 1$. For the MPEX a different system is used because some of the responses are considered neutral. In a finite sample of n students, we want to know the probability of finding n_1 favorable and n_2 unfavorable responses with $n_1 + n_2 = n$. Using the Gaussian approximation to the binomial distribution, we get that the probability of finding fractions $p = \frac{n_1}{n}$ and $q = \frac{n_2}{n}$ is

$$P(p) = Ae^{-(p-p_0)^2}2\sigma^2 \quad (4.1)$$

where A is a normalization constant and

$$\sigma = \sqrt{\frac{p_0q_0}{n}} \quad (4.2)$$

is the standard deviation.

For this distribution, the probability that a sample will have a mean that falls within 1σ of the true mean, p_0 , is 0.684 and the probability that a sample will fall within 2σ of the true mean is 0.954.

4.1.1 Normalized Change

However, in order to characterize an individual's improvement and the improvement of the entire class we need to calculate a normalized change, Marx and Cummings (2007) propose

$$c = \begin{cases} \frac{\text{post-pre}}{100-\text{pre}} & \text{if post} > \text{pre} \\ 0 & \text{if post} = \text{pre}, 0, 100 \\ \frac{\text{post-pre}}{\text{pre}} & \text{post} < \text{pre} \end{cases} \quad (4.3)$$

where post and pre refer to the post-test and pre-test scores out of 100% respectively. We also only include students who have completed the survey both at the beginning and at the end of the term.

Marx and Cummings show that the normalized gain offers some significant advantages, in particular, it allows an instructor to compare increases in scores independently of pre-test scores for many student populations. But this is only the case if the student's performance improves from the pre-test to the post-test. If a student's performance worsens, then an analogous expression is used, which is the ratio of the

actual loss to the maximum possible loss. The advantage of using the normalized change, as opposed to the average normalized gain, is that the normalized change eliminates the low pre-test score bias. Another advantage is that students who have post-test scores that increase or decrease by the same percentage relative to the maximum possible gain or loss obtain the same magnitude of c . As a result, we can calculate the average normalized change, c_{ave} , for a group of students by averaging their individual normalized changes. [9]

4.1.2 Student's t -test

A student's t distribution is applied when the population is assumed to be normally distributed but the sample sizes are small enough that the statistic on which inference is based is not normally distributed because it relies on an uncertain estimate of standard deviation rather than on a precisely known value.

The null hypothesis (H_0) formally describes some aspect of the statistical behavior. It posits an expected value of some population parameter, and the alternative hypothesis covers the other potential values of that parameter. The null hypothesis is treated as valid until the actual behavior of the data contradicts our assumption. Statistical hypothesis testing is used to make a decision about whether two sets of data contradict the null hypothesis. A test on the null hypothesis is to show that the means of two normally distributed populations are equal. Given two data sets, each characterized by its mean, standard deviation and number of data points, we can use some kind of t -test to determine whether the means are distinct from one-another.

The t ratio is more variable and the extreme variants create longer tails for a t -distribution than for a normal distribution. The probability distribution function of t becomes flatter than the normal distribution, especially when a small sample size is involved. The smaller the sample size, the "flatter" the t -distribution becomes

relative to the normal curve. Conversely, as the sample size increases, the distribution of t tends toward normality. For samples greater than 30 the normal distribution and the t -distribution are virtually identical.

Once a t value is determined a p -value can be found using a table of values from Student's t -distribution. If the calculated p -value is below the threshold chosen for statistical significance then the null hypothesis, which usually states that the two groups do not differ is rejected in favor of an alternative hypothesis, which typically states that the groups do differ. [15]

I ran a t -test, in Excel, against all the MPEX pre-test scores and the MPEX post-test scores to show that they are statistically different. After running the test where the two sets of data were paired, we saw that the variance (49.4-33.2) were in fact different enough to run the test assuming unequal variances. Our testing resulted in an absolute value of t equal to 8.322 with a p value equal to 5.92×10^{-15} , proving with 95% confidence that these two data sets (pre and post scores) are indeed different.

4.2 Correlation Results

The typical tests one would employ to establish if there is a statistical difference between the means of two populations might be difficult to interpret. The problem arises from the fact that the individual normalization change values do not represent data. The pre-test and post-test scores are the data, no individual error bars needed. It is important not to confuse the data with the numbers generated by the tools we use to draw conclusions about the data. The normalized change value is not normally distributed, therefore, in general, we should not make conclusions regarding the differences between means. [9]

We will use a correlation transform to determine the extent to which changes

in a particular data set are associated with changes in another data set. Each set contains one of the variables we are interested in comparing. The input data can also be treated as a sample obtained from a larger population, and the correlation transform can be used to test whether the data sets are correlated in the population. The correlation coefficient, r , is a measure of the linear relationship between two data sets. The value of r can range from -1 to $+1$ and is unitless. A value of r near 0 indicates little correlation between the two desired data sets and a value near $+1$ or -1 indicated a high level of positive correlation or negative correlation respectively. A positive correlation refers to an increase in the value of one variable will more likely indicate an increase in the value of the second variable. A correlation coefficient of less than 0 indicated a negative correlation where when one variable shows and increase in value the other variable will show a decrease in value.

If $r = 1$, the two variables are perfectly positively correlated and all values of the data sets lie on a straight line with a positive slope in the x-y plane. If $r = 0$ then the two variables are not correlated and do not have an apparent linear relationship. Finally, if $r = -1$, the two variables are perfectly negatively correlated and all values of the data sets lie on a straight line with a negative slope in the x-y plane. However, this does not mean that the two sets of data are statistically independent. In order to prove independence, I ran a t-test to show with 95% confidence that the distributions of the MPEX pre and post-test scores are indeed different.

When looking at the normalized change against the raw score as shown in, Fig. 4.5 for the pre-test score and Fig. 4.6 for the post-test score, we see a shift in the correlation between the normalized change with the pre-test scores and post-test scores. The pre-test scores have very little to no correlation, r values of $r_{FCI} = 0.133$ and $r_{MPEX} = 0.370$ respectively. There is the resemblance of a faint fanning pattern on the MPEX pre-test score against normalized change with the largest spread toward

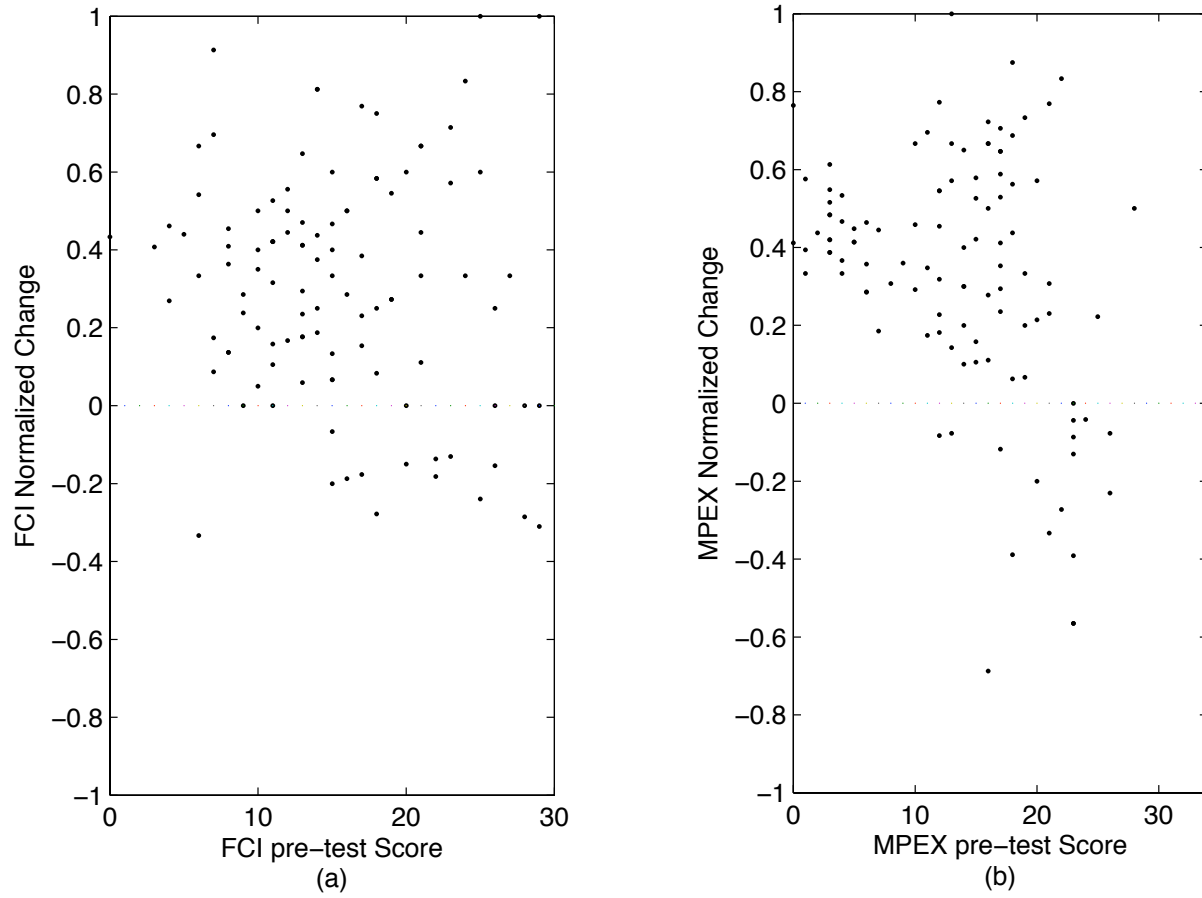


Figure 4.5 Normalized change, c , calculated using pre-test and post-test scores for both the FCI and MPEX plotted against the corresponding raw pre-test score for each of the tests.

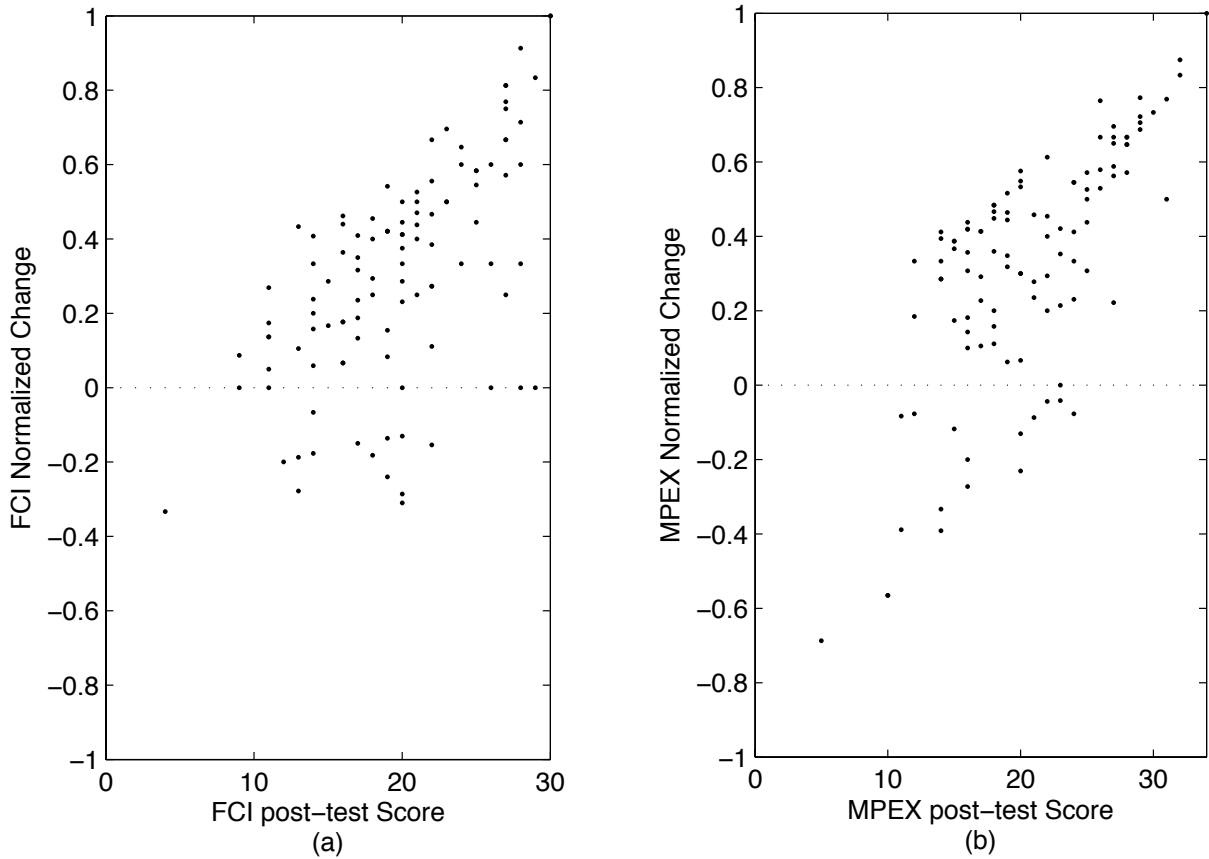


Figure 4.6 Graph (a) shows the raw scores for the FCI post-test plotted against the FCI normalized change. Graph (b) shows student post-test scores on the MPEX against the normalized change calculated using the MPEX pre and post-test scores.

the end of higher scores. The post-tests however, have a much higher correlation with r values of $r_{FCI} = 0.608$ and $r_{MPEX} = 0.709$. This is promising because it shows that those students who scored higher on their post-test scores received the higher gains and those who have low post-test scores didn't gain as much.

4.2.1 FCI and MPEX Correlations and Normalized Change

Unlike in the FCI scores, where the pre and post-test scores of the survey for each year are statistically equivalent, the MPEX scores vary greatly from year to year as shown in Fig. 4.4. The class of 2005 and 2006 are similar as stated above, but the class of 2007 have abnormally low pre-test results. Despite the low pre-test results, the class of 2007 shows the highest increase in overall score on the MPEX post-test yet still below the post-test score of those students in the 2005/2006 class. This shows that even though a particular class may enter with test scores below expected, we are still able to produce gains in student expectations and beliefs. The anomaly of our data set is in the 2008 class scores. While the class had particularly high pre-test scores, there were very few learning gains.

Individuals had both positive and negative gains on the FCI and MPEX across all four years, but overall the scores averaged out to show improvement in their conceptual knowledge as well as their thinking to be more in congruence with professional physicists thinking. Fig. 4.7 shows the normalized change, calculated by Eq. 4.3, for each student on the FCI and MPEX. We see a high percentage of gains in conceptual knowledge. 77% of students scored higher on their FCI post-test than they did on the pre-test. The majority of negative gains resulted from students who scored extremely high on their pre-test, a high pre-test score could produce a negative normalized change with the slip of one question on the post test.

Other information that we can gather from the top graph of Fig. 4.7 is that

the number of students who receive negative gains on the FCI are evenly scattered over the entire tested student population. The bottom graph showing the MPEX normalized change per student number reassures our analysis of the previous graphs (Fig. 4.4) showing that students are indeed scoring higher on the post-test. Again, we see a clumping near the highest student number in the negative normalized change region, but remember that these students are the ones who started out higher than previous years and for the same reasons as the FCI, will show negative results if their post-test answers are off by one or two. What this graph, Fig. 4.7, is able to show more clearly is that there are students in the 2008 class who also made gains on their MPEX scores. Results that other institutions have published [13] [7] on this particular expectations survey have given information that would flip the MPEX normalized change graph about its axis. We can show overall positive gains on the MPEX here at Ithaca College. Interesting note: prior to the class of 2008, only one physics major showed a decline on their MPEX score.

Another useful way to look at the data is to plot students scores on the MPEX versus the FCI. Fig. 4.8 is a plot of the normalized change for both MPEX and FCI plotted against each other. One key feature to note is that 63% of the students (each point represents a student and their gain on both the FCI and MPEX) show a gain on both the FCI and MPEX. Quadrant I represents those students who show an increase in understanding of the concepts of Newtonian Mechanics as well as an increase in their thought process.

Quadrant IV of Fig. 4.8 represents those students who have tested to show an increase in conceptual understanding but decrease in their perceptions on scientific thinking. This quadrant has 14% of all the students that we tested with the majority coming from the class of 2008 (43%).

Noting the raw score against the normalized change is useful in seeing how the

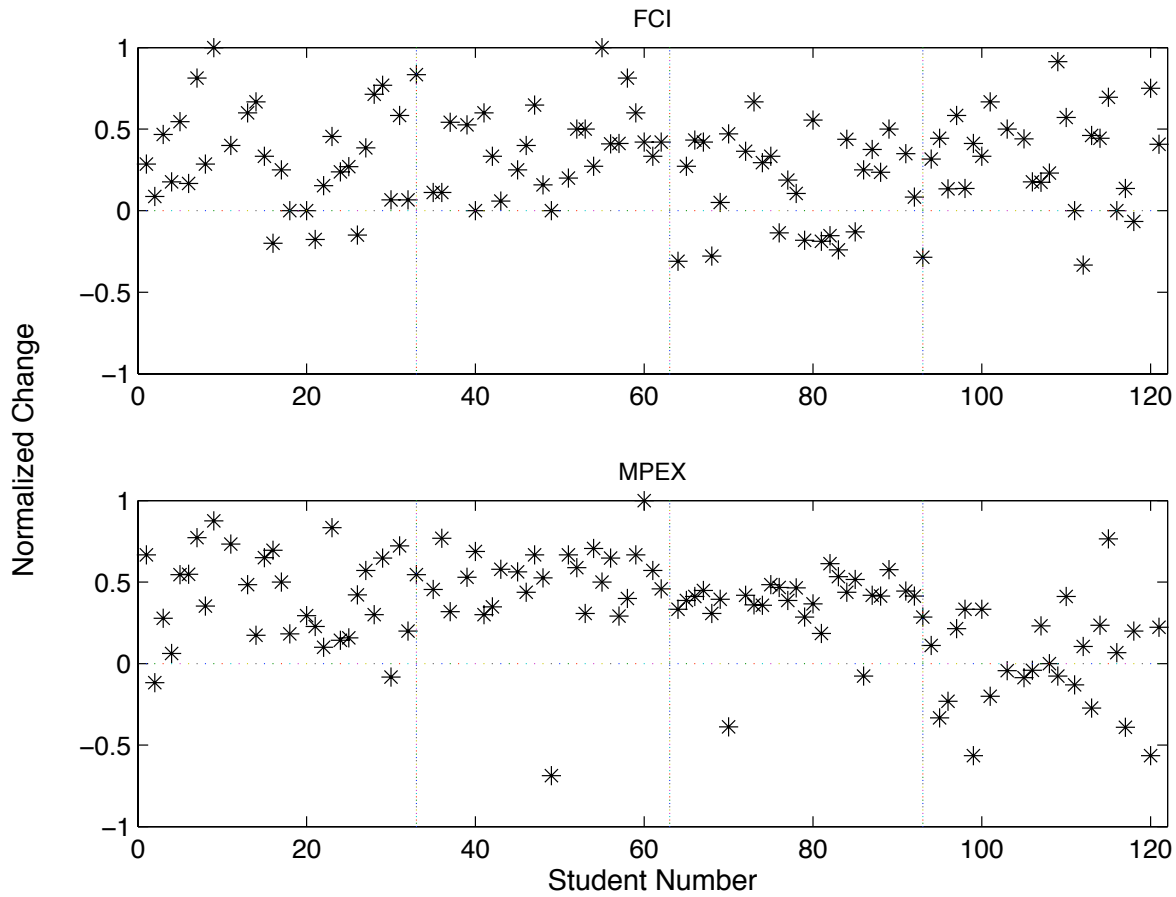


Figure 4.7 This figure shows the normalized change, c , calculated using pre-test and post-test scores, Eq. 4.3 for both the FCI and MPEX plotted against each individual student.

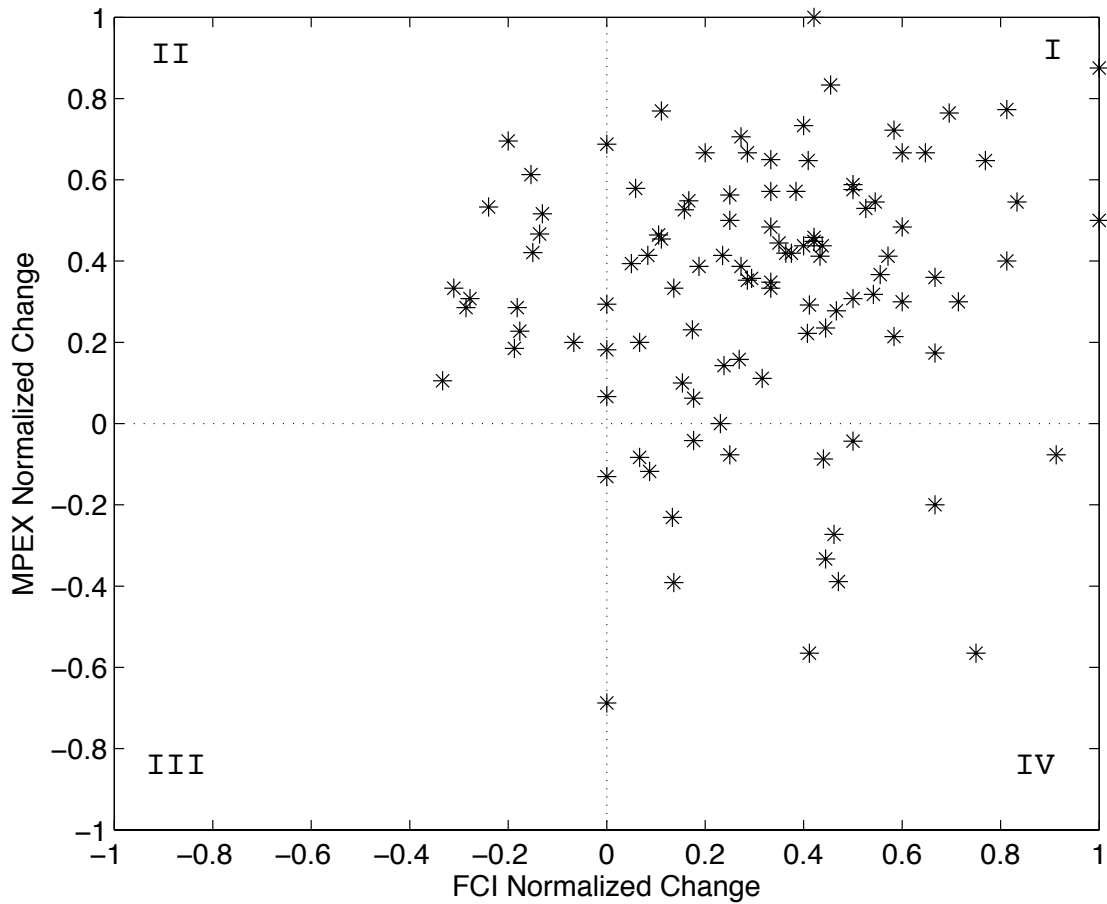


Figure 4.8 This figure shows the normalized change, c , calculated using pre-test and post-test scores for both the FCI and MPEX plotted against each other. The majority of the points are in the first quadrant which represents the students who have a positive gain in the FCI also received an increase in score on the MPEX.

students fair in comparison to each other. But we also want to see how they compare to themselves. We would like to see if there is any way to predict how a student would score on the MPEX based entirely on how they score on the FCI and vice-versa. In Fig. 4.9 I plotted the raw FCI pre-test scores students received against their raw MPEX pre-test scores. There is no correlation between the two pre-test scores, $r = 0.041$, indicating that knowing a student's pre-test score on either test would not help in predicting how they would score on the other. The post-test plot, while still not well correlated, does show a change between the pre and post-test scores. The post-test scores are shifted up and to the right indicating, as stated before, students are scoring higher on the post-test for both the FCI and MPEX.

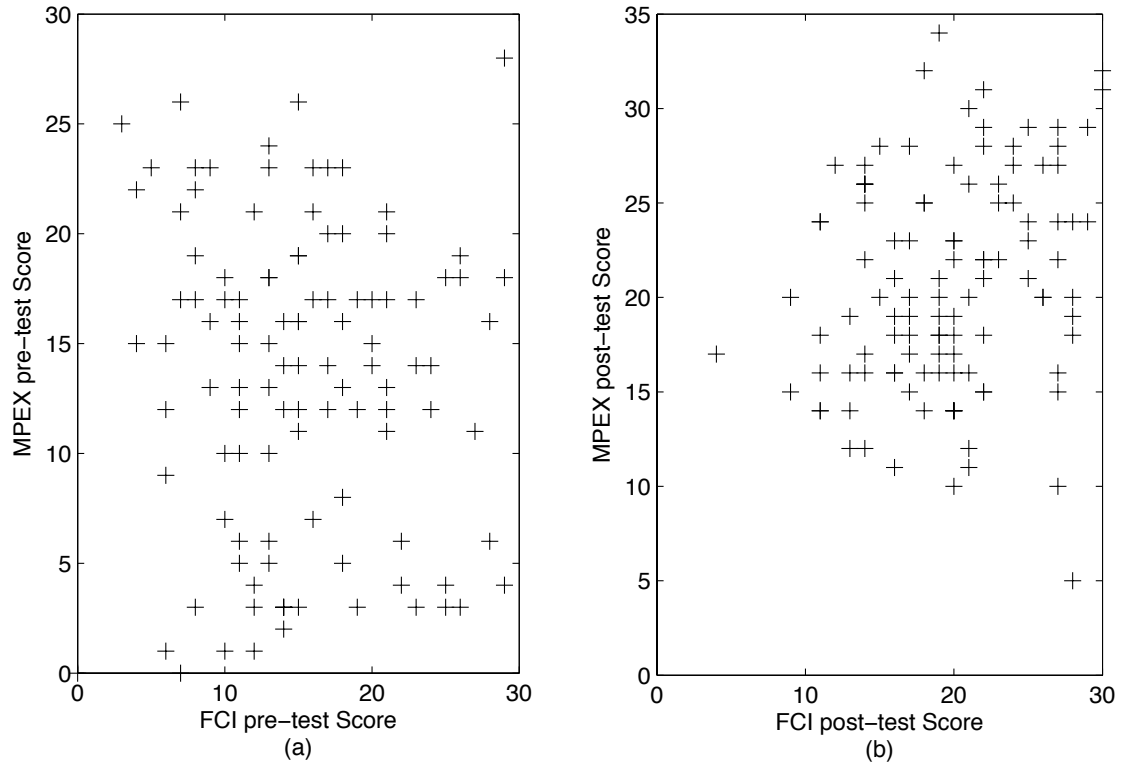


Figure 4.9 Graph (a) shows the correlation between how a student preformed on the MPEX pre-test and their score on the FCI pre-test. Graph (b) shows scores received after the students completed one semester of calculus-based introductory physics. Notice the shift to the right and up on the graph representing higher scores on both the FCI and MPEX.

Chapter 5

Conclusions

Ithaca College students answer the MPEX, on average, to be in $39 \pm 37\%$ congruence to professional physicists prior to taking our calculus-based introductory physics course, overall. After completion of the course the student answers agree with professional physicists answers by $61 \pm 46\%$, overall. Their initial scores match that recorded at other institutions [13] [7]. We suggest that what makes Ithaca College different is implementation of the performance based teaching classroom that facilitates student collaboration, Sec. 3.1, and the professors dedication to the time and energy spent on context rich problem solving, Sec. 3.4. Students find that they are able to reason complex physics problems out using a proper skill set rather than look up what values belonging in a certain equation. There is a transition in the students thinking that steers them away from just finding the “right” answer and gets them to figure physics problems out in a systematic way.

5.1 Summary

We administered two surveys during the second class period and during the final exam of a calculus-based introductory physics course on Newtonian Mechanics. Starting Fall of 2005 there have been four classes and a total of 121 students in our study. The two surveys used were the Force Concepts Inventory (FCI) and the Maryland Physics Expectations Survey (MPEX). Results from the FCI showed students here at Ithaca College are congruent with other liberal arts colleges and showed positive gains in their understanding of Newtonian Mechanics at the end of the course. When analyzing the MPEX results, we found that Ithaca College students, overall, show positive gains in their thought process from beginning to end.

5.2 Future Work

Future work will be to interview students. It seems like the best way to get information and see what they are really thinking. More work needs to be done to pinpoint what it is about Ithaca College seeing MPEX gains while other schools are not. Another interesting question is where is the transition point when you start thinking like all the other professional physicists? Is it your senior year, graduate school, PHD? These surveys need to be given at multiple levels of education. A more immediate question that can be answered is what will happen to the student scores when the professor is changed but not the implementations of the context-rich problems? This is data that will be produced this upcoming year.

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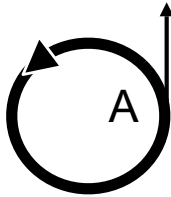
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Appendix A

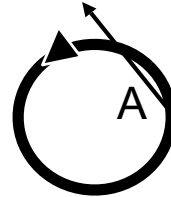
Force Concept Inventory

A. A car is driving on a rough horizontal circular track at a constant speed. Which of the following diagrams best illustrates the direction of the car after it hits an icy patch (no friction) on the road at point A?

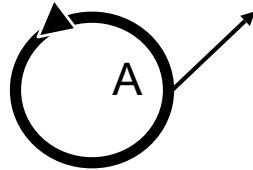
1.



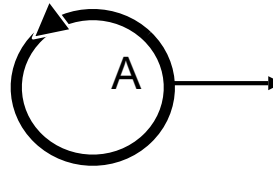
2.



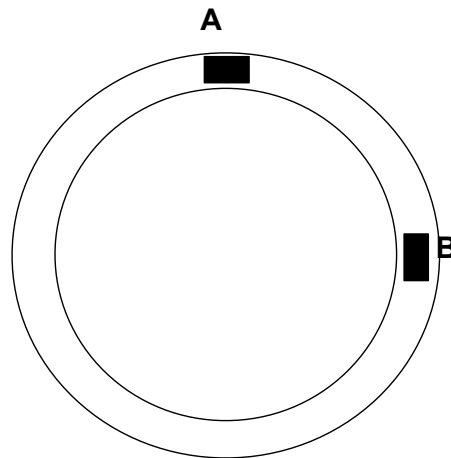
3.



4.



B. Two cars with identical tires are driving on a rough horizontal circular track. Each car is driving at a constant speed such that it is just on the verge of slipping off of the track. The mass of car A is twice the mass of car B. How are the speeds of the cars related?

1. $v_A < v_B$ 2. $v_A = v_B$ 3. $v_A > v_B$ 4. $v_A = v_B = 0 \text{ m/s}$ 

C. A box sits at rest on a horizontal frictionless surface. A constant force is applied for a short time interval, Δt , after which the box moves with a constant speed. To reach the same final speed with a force that is half as big, the force must act on the box for a time interval that is

1. four times as long as Δt .
2. twice as long as Δt .
3. equal to Δt .
4. half as long as Δt .
5. one quarter as long as Δt .

D. Same situation: A box sits at rest on a horizontal frictionless surface. A constant force is applied for a short time interval, Δt , after which the box moves with a constant speed. We now repeat the experiment with the same force and time interval, but the box has twice the mass of the original box, the new final velocity will be

1. four times larger than before.
2. twice as large as before.
3. the same as before.
4. $1/2$ as large as before.
5. one quarter as large as before.

E. A mass is attached to a spring, which is compressed by a distance (x) from its equilibrium point by a force. After the spring is released and as it returns to its equilibrium point

1. the magnitude of the acceleration of the mass will decrease.
2. the magnitude of the acceleration of the mass will increase.
3. the magnitude of the acceleration of the mass will depend on the direction (+ or -) of its motion.
4. the magnitude of the acceleration of the mass will be constant.

Figure A.1 **Not actual survey questions.** Here are example questions used in our calculus-based Newtonian Mechanics Introductory physics class to probe student understanding of physics concepts. The actual questions on the FCI cannot be used for test security reasons.

Appendix B

Maryland Physics Expectations

Survey



Student Expectations in University Physics: *The Maryland Physics Expectations Survey*

Here are 34 statements which may or may not describe your beliefs about this course. 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
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Answer the questions by circling the number that best expresses your feeling. Work quickly. Don't over-elaborate the meaning of each statement. They are meant to be taken as straightforward and simple. If you don't understand a statement, leave it blank. If you understand, but have no strong opinion, circle 3. If an item combines two statements and you disagree with either one, choose 1 or 2.

1	All I need to do to understand most of the basic ideas in this course is just read the text, work most of the problems, and/or pay close attention in class.	1 2 3 4 5
2	All I learn from a derivation or proof of a formula is that the formula obtained is valid and that it is OK to use it in problems.	1 2 3 4 5
3	I go over my class notes carefully to prepare for tests in this course.	1 2 3 4 5
4	"Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number.	1 2 3 4 5
5	Learning physics made me change some of my ideas about how the physical world works.	1 2 3 4 5
6	I spend a lot of time figuring out and understanding at least some of the derivations or proofs given either in class or in the text.	1 2 3 4 5
7	I read the text in detail and work through many of the examples given there.	1 2 3 4 5
8	In this course, I do not expect to understand equations in an intuitive sense; they must just be taken as givens.	1 2 3 4 5
9	The best way for me to learn physics is by solving many problems rather than by carefully analyzing a few in detail.	1 2 3 4 5
10	Physical laws have little relation to what I experience in the real world.	1 2 3 4 5
11	A good understanding of physics is necessary for me to achieve my career goals. A good grade in this course is not enough.	1 2 3 4 5
12	Knowledge in physics consists of many pieces of information each of which applies primarily to a specific situation.	1 2 3 4 5
13	My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it.	1 2 3 4 5
14	Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook.	1 2 3 4 5
15	In doing a physics problem, if my calculation gives a result that differs significantly from what I expect, I'd have to trust the calculation.	1 2 3 4 5

16	The derivations or proofs of equations in class or in the text has little to do with solving problems or with the skills I need to succeed in this course.	1 2 3 4 5
17	Only very few specially qualified people are capable of really understanding physics.	1 2 3 4 5
18	To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	1 2 3 4 5
19	The most crucial thing in solving a physics problem is finding the right equation to use.	1 2 3 4 5
20	If I don't remember a particular equation needed for a problem in an exam there's nothing much I can do (legally!) to come up with it.	1 2 3 4 5
21	If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable. (Assume the answer is not in the back of the book.)	1 2 3 4 5
22	Physics is related to the real world and it sometimes helps to think about the connection, but it is rarely essential for what I have to do in this course.	1 2 3 4 5
23	The main skill I get out of this course is learning how to solve physics problems.	1 2 3 4 5
24	The results of an exam don't give me any useful guidance to improve my understanding of the course material. All the learning associated with an exam is in the studying I do before it takes place.	1 2 3 4 5
25	Learning physics helps me understand situations in my everyday life.	1 2 3 4 5
26	When I solve most exam or homework problems, I explicitly think about the concepts that underlie the problem.	1 2 3 4 5
27	"Understanding" physics basically means being able to recall something you've read or been shown.	1 2 3 4 5
28	Spending a lot of time (half an hour or more) working on a problem is a waste of time. If I don't make progress quickly, I'd be better off asking someone who knows more than I do.	1 2 3 4 5
29	A significant problem in this course is being able to memorize all the information I need to know.	1 2 3 4 5
30	The main skill I get out of this course is to learn how to reason logically about the physical world.	1 2 3 4 5
31	I use the mistakes I make on homework and on exam problems as clues to what I need to do to understand the material better.	1 2 3 4 5
32	To be able to use an equation in a problem (particularly in a problem that I haven't seen before), I need to know more than what each term in the equation represents.	1 2 3 4 5
33	It is possible to pass this course (get a "C" or better) without understanding physics very well.	1 2 3 4 5
34	Learning physics requires that I substantially rethink, restructure, and reorganize the information that I am given in class and/or in the text.	1 2 3 4 5

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Figure B.1 ”**Product Warning Label:** Note that individual items from this survey should not be used to evaluate individual students. On any single item, students may have atypical interpretations or special circumstances which make the ’non-expert’ answer the best answer for that student. Furthermore, students often think that they function in one fashion and actually behave differently. For the diagnosis of the difficulties of individual students more detailed observation is required. This survey is primarily intended to evaluate the impact of one or more semesters of instruction on an overall class. It can be used to illuminate some of the student reactions to instruction of a class that are not observable using traditional evaluations. In this context, it, together with evaluations of student learning of content, can be used as a guide for improving instruction.” [12]