INTERACTIVE-ENGAGEMENT VS. COOKBOOK LABORATORY PROCEDURES
IN MBL MECHANICS EXERCISES

by

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A DISSERTATION

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In recent years, much work has been done to investigate physics teaching techniques that facilitate conceptual learning in mechanics. This study compared the effectiveness of microcomputer-based laboratory procedures that were written in a traditional “cookbook” style to interactive-engagement procedures that covered the same material with the same experimental apparatus for equal times.

Two lab sections in an introductory trig-based physics course at a small private college participated in different lab exercises for nine weeks. One section completed nine chapters of the interactive-engagement lab curriculum, RealTime Physics. The other participated in cookbook labs that were written for this study to cover the same material. Gain in conceptual mechanics understanding was measured with a pre-instruction/post-instruction administration of the Force Concept Inventory. Both groups completed the conceptual homework included in the RealTime Physics exercises. This procedure was repeated in a second nine-week phase, in which neither group was assigned the homework.

Average normalized gains for the interactive-engagement and cookbook groups were $h = 0.471$ and $h = 0.392$, respectively. In the second phase (without the homework), they were $h = 0.480$ and $h = 0.334$. In the second phase, the normalized
gain for the interactive-engagement group was 0.568 s.d. higher than the cookbook group ($N = 27, p = 0.076$).

For the interactive-engagement groups in the two phases, the homework did not make a difference in FCI gains. The pooled average normalized gain for these two groups was equal to $h = 0.476$ ($N = 27$), which is comparable to the average gain measured for the interactive-engagement groups in Hake’s large data set in 1998.

Small differences in satisfaction and perceived effectiveness were measured between the interactive-engagement and cookbook groups. These differences generally favored the cookbook labs.
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Soli Deo Gloria
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CHAPTER I
INTRODUCTION

Context

The educational laboratory has been used as an instructional tool in the physics classroom for many years. As early as 1886, Harvard University published a list of physics experiments to be completed by high school students who wished to enroll at Harvard (Moyer, 1976). Physics teachers recognize the importance of educational laboratory exercises in assisting the acquisition of laboratory skills, introducing the processes of scientific inquiry, and as an instructional strategy to help students learn physics concepts.

There have been many physics curricula developed for introductory courses in recent years. Well-known current curriculum projects making use of specialized laboratory resources include RealTime Physics (Sokoloff, Thornton, & Laws, 1999), Tools for Scientific Thinking (Thornton, 1987), Socratic Dialogue Inducing Labs (Hake, 1987), and The Modeling Workshop Project (Halloun & Hestenes, 1987). Many of these modern laboratory curricula have been developed using results from physics education research. The laboratory procedures in these exercises differ in many ways from traditional labs. In addition to the increased availability of technological tools in the modern labs, these laboratory exercises require the learner to be an active inquirer, solving problems and focusing attention on the ideas and processes of physics.

Old-style labs, on the other hand, are often derided in the research literature as “cookbook” labs. The lab manuals of twenty years ago generally contained explicit
instructions in a step-by-step procedure that choreographed each action taken by the learner, with reflective questions saved for the end of the lab exercise. After “taking data,” the students were often required to write a report in some prescribed format, where they would be expected to synthesize the main points of the exercise into some sort of cohesive conceptual aggregate.

Physics laboratory curricula written in the last decade often include the use of Microcomputer Based Laboratory (MBL) equipment. These curricula were originally developed by educators at postsecondary schools, especially Tufts University (Thornton & Sokoloff, 1990). Measuring devices that interface with a computer give students in the physics laboratory unprecedented access to real-time measurements of physical phenomena.

Purpose of the Study

Physics education researchers have made progress in acquiring an understanding of instructional strategies that improve the conceptual learning of physics students. But much of the data that has been collected has failed to isolate single instructional treatments from instructional regimes that use a variety of teaching strategies. This study has focused on one particular type of instructional tool in physics, the educational laboratory. By isolating this treatment in a controlled experiment, an attempt has been made to determine its importance in producing a change in conceptual mechanics knowledge.

Several researchers have considered laboratory exercises as a separate factor in student learning. Some, for instance, have compared the effectiveness of modern MBL labs to traditional lecture instruction (Redish, Saul, & Steinberg, 1997). Some data also
supports the effectiveness of the use of MBL instructional methods for conceptual learning gains (Workshop Physics project, 2001).

Perhaps the effectiveness of these laboratory curricula resides in their use of MBL equipment itself. Or is the enhanced effectiveness due to the fact that learners are actively engaged by the procedures in this sort of laboratory? Would physics students learn mechanical concepts just as efficiently in a cookbook lab that makes use of MBL instruments? Does the benefit reside in the active-learning characteristics of the procedure? This study has tried to separate these issues.

Research Questions

In this research study, the following questions were investigated:

RQ1. Are there significant differences in the conceptual mechanics knowledge gain (as measured by the FCI) for students who participate in active-learning MBL physics laboratories, compared to students who participate in equal-time exercises with cookbook procedures that also make use of MBL equipment?

RQ2. Can the use of interactive-engagement laboratories in conjunction with an otherwise traditional classroom environment produce significant gains in conceptual learning?

RQ3. How do the satisfaction and perceived effectiveness of the exercises compare for students in the two groups?
Significance of the Study

While many modern active-learning instructional techniques have been widely adopted, there is still much resistance to change. There are few, if any, active proponents of cookbook labs in the physics education research community. However, it is likely that many individual physics instructors continue to use traditional lab exercises that rely on cookbook procedures. It is therefore important to determine if there is an educational benefit to using active-learning procedures in the educational physics laboratory that surpasses the benefit produced by these traditional procedures.

Many physics teachers who cling to traditional instructional techniques use some kind of laboratory exercises, though they may possess characteristics that would be described as “traditional.” Previous studies that have compared active-learning MBL labs to lecture have not made a comparison with traditional labs. The treatment factor varied in this experiment was the engagement level of the laboratory procedure. By isolating this particular characteristic, this study provides a direct comparison of a course that makes use of MBL equipment and interactive-engagement techniques in its laboratory component, and one that uses the newest equipment with old-fashioned instructional procedures.

In summary, this study will evaluate the effectiveness of active learning procedures in the introductory physics laboratory while holding constant as many other factors as possible. This will afford individual physics instructors more information upon which to make decisions about the nature of the laboratory exercises they provide for their students.
CHAPTER II
REVIEW OF LITERATURE

Introduction

Science educators are constantly striving to improve the quality of education. In this chapter, historical reform efforts will be described and current ideas about instructional theory will be summarized. In order to localize the present study in a research base, this review of literature will focus on educational research efforts in the field of physics, and will particularly emphasize Newtonian mechanics.

In the field of mechanics, physics education researchers have a unique advantage over their counterparts in many other disciplines, in that there exists a short, widely used evaluation instrument, namely the Force Concept Inventory. This chapter will review the development and history of the Force Concept Inventory, synopsize recent research in conceptual mechanics education, and finally discuss research studies that have focussed on the educational physics laboratory.

Historical Perspectives on Educational Reform

Trowbridge, Bybee, & Powell identify two distinct eras of reform in the last forty years. A “Golden Age” took place roughly from 1958-1988, and a “Modern Era” dates from 1988 to the present (2000). Each of these eras has been characterized by a particular psychological theory that has guided its development. The Golden Era featured an emphasis on behavioral psychology and Piaget’s theory of cognitive development, while the Modern Era stresses constructivism and inquiry learning.
The Golden Era (1958-1988). The Golden Era of reform was ushered in by the launching of Sputnik in 1957, which caused a huge influx of federal money for the development of new science curricula and a large increase in national attention to the importance of science education. These reforms followed an earlier round of reform that was precipitated by World War II (Donahue, 1993). During the early stages of the Cold War, educators were pushed by federal policy to produce unambiguously measurable learning outcomes. In this era science educators moved away from the curriculum strategies of the first half of the century that accentuated technical and social applications of technology, and moved toward learning the abstractions and theories of science.

During the 1960s, an alphabet soup of curriculum programs was produced. These included the Physical Science Study Committee (Physical Science Study Committee, 1957), the Earth Science Curriculum Project (Earth Science Curriculum Project, 1965), and several others which facilitated students’ acquisition of scientific knowledge.

A typical study during the 1970s (Griffiths, 1975) measured the cognitive development level of students studying physics, and studied whether a level of development had been attained that would allow understanding of physics concepts. The author concluded that many students had not reached Piaget’s formal operation level of cognitive development and could therefore actually be “harmed” by physics instruction.

Prigo (1978) attempted to develop a lecture course that was sensitive to the cognitive development level of its students. Given that about 50% of college freshmen still operate at the concrete operational level of thinking, he felt it was necessary to focus the attention of his course on the “objects” of physics, before it was appropriate for the theories of the discipline to be considered.
Liberman & Hudson (1979) measured a correlation ($r = 0.49$) between logical abilities and academic achievement in physics. They suggested that formal operation reasoning abilities are a necessary precondition to learning physics.

Classifying students by cognitive ability level and allowing the “cream to rise to the top” does not mesh with prevailing notions of instruction. Present researchers focus on the methods of instruction, searching for techniques that will be helpful to students at all developmental levels.

**Overview of the Current State of Physics Education Research**

The state of the current reform movement in physics education has been summarized by Mestre (1994). The main obstacle to learning physics he describes in his paper is highly representative of that found in much of the present literature, namely student misconceptions.

**Constructivism.** In constructivist theory– the dominant paradigm among science education researchers– all knowledge needs to be “constructed” by students in a highly contextual way. Students do not come to science classes with a “blank slate,” ready to have knowledge transmitted to them by a content expert, but rather need to relate new knowledge to that which is already present in their minds. This process is hampered by the presence of misconceptions, or naïve beliefs. These beliefs need to be “flushed out” into the open by some socially mediated process; a dialogue with the teacher, small group discussions, experience with manipulable items in the laboratory, or a combination of these techniques. Once the students are confronted with the inadequacy of their misconceptions, they can begin the process of building accurate conceptual knowledge.
Constructivism is a movement with many diverse proponents, so it is not surprising that many differing opinions exist as to what constructivism is and what it is not. Brooks and Brooks (1993) offer one perspective, by listing “Five Principles of Constructivist Classrooms,” as:

1. Teachers seek and value their students’ point of view.
2. Classroom activities challenge students’ suppositions.
3. Teachers pose problems of emerging relevance.
4. Teachers build lessons around primary concepts and “big” ideas.

This learning theory is compatible with the “inquiry learning” instructional approach, which focuses on helping students pose answerable questions, devise a procedure to answer the question, and communicate the results (Trowbridge et al., 2000). Various national science standards documents endorse inquiry learning as an effective and important instructional strategy (American Association for the Advancement of Science, 1989; National Research Council, 1996).

Much effort has been devoted to the discovery and measurement of misconceptions in the general population. Misconceptions have been found to be very common, even among science teachers. It is important that instructors are aware of the nature of these misconceptions, so that they can be properly addressed during instruction.

This approach contrasts with traditional instruction, which takes a “transmittalist” approach to instruction. In this system, information is presented to the students through lectures, while students sit passively and absorb it. Transmittalists assume that success in
learning largely depends on the clarity of the presentation, and the charisma of the teacher (McDermott, 1999).

**Resistance to Reform.** Reformers often wrestle with the fact that their agenda remains uncommon in modern science classrooms. Redish (2000) states, for example, that “Although there has been an intellectual explosion in physics curriculum development, the actual impact on teaching at the tertiary level has so far been small. Most innovations remain local, ignore the results of physics education research and cognitive science, and are ineffective.” Mestre (1994) offers two reasons that account for the same problem: teachers are merely continuing a “vicious cycle,” teaching as they were taught, and that they are overwhelmed by the need to cover an ever-increasing amount of material. Redish, on the other hand, speculates that the main obstacle to the implementation of reform comes from basic misconceptions that instructors have about how students learn.

**Breadth vs. Depth.** Mestre’s second point underscores another fault line between the modern reform era and the previous reform era: breadth versus depth. In the new era of science education reform, “less is more” (Speece, 1993). Many reformers argue that it is more important to cover the meaty concepts of a discipline in depth, to avoid a curriculum that is “a mile wide and an inch deep.” (Schmidt, McKnight, & Raizen, 1997) Some have characterized this debate as “the religious question of whether it’s better to learn 10% of 90% of the subject or 90% of 10% of the subject.” (Brooks, 2000) Brooks and Brooks speak to this issue very clearly, by saying

Constructivist teachers have discovered that the prescribed scope, sequence, and timeline often interferes with their ability to help students understand complex
concepts. Rigid timelines are also at odds with research on how human beings form meaningful theories about the ways the world works (Duckworth 1986), how students and teachers develop an appreciation of knowledge and understanding (Eisner 1985), and how one creates the disposition to inquire about phenomena not fully understood (Katz 1985). Most curriculums simply pack too much information into too little time—at a significant cost to the learner. Teachers everywhere lament how quickly students forget and how little of what they initially remembered they retain over time. Our present curricular structure has engineered that outcome. Students haven't forgotten; they never learned that which we assumed they had. In demanding coverage of a broad landscape of material, we often win the battle but lose the war. We expose students to the material and prepare them for the tests, but we don't allow them to learn the concepts. (p. 39-40)

Filter or Pump? Although the philosophical underpinnings of the two reform eras were instrumental in producing the differences described above, one could argue that the driving force that has produced the shift to the modern paradigm was not theoretical, but rather a change in goals. The Sputnik-inspired reforms of the 1960s were designed to focus primarily on the high-achieving students bound for college, in order to produce an elite cadre of scientists and engineers who would ensure the technological superiority of the United States for years to come. An extreme example of this point of view was voiced in 1942:

Excoriating the “extreme phase of mass and moron worship” which he saw in the public schools, Thomas Cope of the University of Pennsylvania believed physics
should be used to separate the elite from “the horde of less intelligent pupils which today overcrowds the public secondary schools.” He asked, “Is our high school boy able to master Millikan and Gale’s *Physics* and is he willing to make the necessary effort? If yes he is my aristocrat, if not, he belongs to my masses.” (Cope, 1942; quoted in Donahue, 1993, p. 330)

When voices are raised in opposition to current reform initiatives, the point of disagreement often breaks down to this question of goals: Do we wish to continue broad traditional coverage of topics, which may act as a “filter,” weeding out low-achievers, or a “pump” (Steen, 1988), following the dictates of the National Science Education Standards (National Research Council, 1996), which call for “science for all?” Anti-reformers might object to the present emphases by saying “What’s wrong with the old methods? I learned fine that way,” to which a reformer would reply “But that’s how *you* learned it. Were you an average student? What about the medium and low-achievers who need to learn science?” The debate can be contentious, with one author sarcastically asking “Why Change, Been Doin’ It This Way For 4000 Years!” (Flowers, 2000)

**The Reform Agenda**

Researchers propose several strategies to help students acquire the skills and strategies necessary for learning physics. First of all, teachers need to be aware of the obstacles students face when learning physics. This implies they need focus on the learner, and not only display competence in their subject. For instance, if an instructor doesn’t realize that some students lack prerequisite math skills, those students are likely to fail. The teacher therefore needs to solicit feedback from the students, in order to help them overcome any skill deficiencies they might have. This “feedback principle” is also
of prime importance in helping students overcome their misconceptions. Merely distributing information without engaging students in any kind of active learning activities that address misconceptions will increase the likelihood of failure.

Teaching methods seem to be of extreme importance in helping students acquire conceptual knowledge about mechanics. In important papers that will be considered in some detail below (Hake, 1998a; Hake, 1998b), Hake has shown instructional methods lacking elements of “interactive engagement” to be ineffective in helping students acquire conceptual knowledge, as measured by instruments like the Force Concept Inventory. These results have led Hestenes (1998) to suggest that “lectures are (perhaps, totally) ineffective in teaching the basic concepts of physics, even apart from other evidence pointing to the same conclusion.” (p. 466) Similarly, Redish states that “as physics teachers we fail to make an impact on the way a majority of our students think about the world.” (1994, p. 796).

The Force Concept Inventory

The Force Concept Inventory (FCI) is a unique instrument. In a post to the Classics-L listserv on May 25, 1999, Tompkins wrote:

The neat thing about physics is that there is a pretty good instrument called the Force Concept Inventory, which basically tests student understanding of principles that are counter-intuitive-- that is, it is a measure not of “binge-and-purge” learning but of deeper understanding.

The above quote demonstrates that the FCI has even become known outside the physics education community. Within that community it is the most widely used diagnostic tool in existence, and has been cited in dozens of research articles.
Origins of the FCI. The FCI was introduced by Hestenes, Wells and Swackhamer in 1992. This instrument evolved from the earlier Mechanics Diagnostic Test (Halloun & Hestenes, 1985a) and was revised slightly in 1995. Consisting of thirty multiple-choice questions, the FCI was designed to measure students’ conceptual mastery of Newtonian mechanics. Although experienced physics problem-solvers familiar with the FCI generally find answers to the questions to be obvious and indisputable, novices score very poorly on the instrument, particularly since the distracter responses were designed to match common misconceptions.

The FCI is commonly used to measure the effect of an educational treatment, through pre-instruction and post-instruction administration. In this type of design, educational researchers measure the pretest and posttest scores in order to calculate the gain achieved through some instructional treatment regime.

By 1998, David Hestenes had data from more than 20,000 students in 300 physics classes, ranging from high school to graduate school (Hestenes, 1998). Eric Mazur has included the FCI in his popular book, Peer Instruction (1997). The instrument is unique in its ubiquity. The Conceptual Astronomy and Physics Education Research Team at Montana State University even advertises its Astronomy Diagnostics Test as the “FCI for astronomy” on its departmental webpage (Montana State University, 2001).

Assessing Instructional Reform

The FCI has been an important tool in assessing the effectiveness of various educational treatments in introductory-level physics courses. Halloun and Hestenes (1985a) summarized the findings of several studies from the early 1980s regarding common-sense beliefs about motion as:
1. Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses.

2. Common sense beliefs are very stable, and conventional physics instruction does little to change them. (p. 1043)

Richard Hake’s Study. The search for the most effective means to bring about changes in these beliefs eventually led Richard Hake (1998a; 1998b) to compare gains in the FCI and Mechanics Diagnostic Test for courses that used “traditional” instruction to those using “interactive-engagement” methods.

Hake solicited data from sixty-two introductory physics courses enrolling a total of 6542 students. Forty-eight of the courses were classified as interactive-engagement courses, with the remaining fourteen labeled as traditional. Hake averaged the pretest and posttest scores for each course in the two groups and used this data to calculate the average normalized gain for each class, \( \text{Gain}_{\text{normalized}} = h = \frac{\text{post} - \text{pre}}{1 - \text{pre}} \) (where \( \text{pre} \) and \( \text{post} \) are the ratios of the number correct to the total possible), which he then plotted vs. the pretest score. This diagram has come to be known as a Hake Plot, and the normalized gain is often referred to as the Hake Factor, \( h \) (Francis, Adams, & Noonan, 1998; Redish et al., 1997). A schematic of the Hake Plot is shown in Figure 2.1. Since the gain of each student is limited to 100% minus the percentage earned on the pretest, all points lie in the shaded triangular region. Hake showed that classes with similar instructional approaches tend to lie on straight lines passing through the point (100,0). High-gain courses that make use of interactive-engagement instructional methods lie closer to the
top of the shaded region (Line a in the diagram), while traditional instruction tends to produce gains that lie on lines closer to the horizontal axis (Line b).

Figure 2.1. A schematic diagram of the Hake Plot. Class average gains are plotted against pretest scores. Interactive-engagement courses tend to cluster along lines closer to the top of the shaded region, with traditional courses closer to the bottom.

In his paper, Hake defined interactive-engagement methods as “those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors” (p. 65). Hake includes MBL exercises as one of his interactive engagement components. The interactive engagement group of courses experienced an average gain of 0.48 ± 0.14 (std. dev.), while the traditional courses had an average gain of 0.23 ± 0.04 (std. dev.). The difference in these
average gains, $0.48 - 0.23 = 0.25$, represents an effect size of 1.8 standard deviations of the interactive-engagement courses (0.14) and 6.2 standard deviations of the traditional group (0.04).

No challenges to Hake’s study have appeared in the literature. A significant amount of discourse regarding the validity of the Hake study is found on electronic bulletin boards. For example, in a post to the PHYS-LRNR listserv Ron Greene stated that “The statement below [that Hake’s study demonstrated substantial learning gains with interactive-engagement methods] has not YET been demonstrated because active vs. inactive learning was not the only relevant distinction between the two groups.” (2000) Hake responded to Greene’s statement in a subsequent listserv post, retracting the word “demonstrated,” but defending the methodology of the study (Hake, 2000). Issues in Hake’s study that are concerned with laboratory work in particular will be considered in more detail in a following section.

Other Uses of the FCI. Francis, Adams & Noonan (1998) administered the FCI to students who had taken an introductory physics course as many as four years earlier, in order to see if high scores on the exam remained fixed. Since there was such a long delay following instruction, the authors reasoned that students who had scored well by memorizing the “right answers” would have been likely to forget them by then. If, on the other hand, high scores had been achieved through the acquisition of a truly Newtonian worldview, the scores would remain high. With $N = 127$, they found that FCI scores were lower by an average of only seven percentage points, with the students having the greatest delay since taking the course actually showing the smallest difference. The
authors concluded that this persistence of scores suggests an enduring shift in beliefs
about motion.

Saperstein (1995) attempted to determine if FCI scores tend to rise for early
teenage students through “living,” without receiving any sort of formal physics
instruction. By comparing FCI scores for a group of 40 girls of age 12 ± 0.5 to published
pretest scores of high school seniors and college freshmen, Saperstein concluded that
students experience a gain in FCI scores of (2.3 ± 1.2)% merely through everyday life.

Other researchers have considered the format of the FCI in particular. These
include two studies that have compared multiple-choice responses to free-response
answers on the FCI (Rebello & Zollman, 2000; Steinberg & Sabella, 1997), and one that
used animated applet simulations on the exam’s answers, in place of static printed
alternatives (Dancy, Titus, & Beichner, 2000).

Validity and Reliability of the FCI

When Hestenes, Wells & Swackhamer developed the FCI, they identified six
categorical dimensions as part of a comprehensive Newtonian force concept (1992):

1. Kinematics
2. First Law
3. Second Law
4. Third Law
5. Superposition Principle
6. Kinds of Force (p. 142)

Items in the exam are keyed specifically to each of these six dimensions. In each
dimension, commonsense misconceptions, as collected in student interviews by Halloun
and Hestenes (1985b), were used to generate distracter options in the corresponding items. There are six categories in which commonsense misconceptions occur, those being:

1. Kinematics
2. Impetus
3. Active Force
4. Action/Reaction Pairs
5. Concatenation of Influences
6. Other Influences on Motion (Hestenes et al., 1992, p. 143-145)

Validity. To validate the FCI, the authors made use of validation work done on its precursor, the Mechanics Diagnostic Test (Halloun & Hestenes, 1985a). In this process, a draft of the test was shared with physics professors and graduate students, adopting some of their suggested revisions. The test was then given to a panel of graduate students, all of whom were able to agree on the correct answers. Interviews were then conducted with high school students who had taken the test, to test for understanding of the questions. Then tests taken by “A” students in a University Physics course were examined for patterns of common misunderstandings.

Reliability. The reliability of the test was established through interviews with students who had taken the test, with the investigators finding excellent agreement between the way students thought and the answers they gave. The Modeling Workshop project at Arizona State University has collected FCI data from some 20,000 high school students and has calculated Cronbach’s coefficient alpha, which measures the instrument’s reliability. They have obtained coefficient alpha values of “mid .80s to the
mid .90s” for FCI posttests and “high .60s to mid .70s” for FCI pretest scores. (Popp, 2000). The alpha coefficient varies from 0 to 1, where higher values indicate greater reliability, and values in the range of 0.7 to 0.8 are generally considered acceptable in social science research (Santos, 1999).

**Huffman and Heller’s Argument.** Huffman and Heller (1995) used a factor-analysis technique to argue that there is not actually a single “force concept” that is measured by the FCI. They examined FCI test data for 145 high school and 750 university students and found that there were only three clusters of questions that grouped together in a statistically significant way. These clusters were not strongly associated with single conceptual dimensions in the FCI. From this they concluded that “the items on the FCI are only loosely related,” (p. 140). They further assert that since students have ill-formed Newtonian mechanical concepts, the FCI is unable to measure a unified concept, but only measures “bits and pieces” of student understanding.

Responding to this, Hestenes and Halloun (1995) said that this is to be expected, since the data was collected from a non-Newtonian population, and the subjects therefore have no Newtonian force concept that can be measured.

The argument continued through two other papers (Halloun & Hestenes, 1996; Heller & Huffman, 1995). Much common ground was established in these subsequent papers, but neither group conceded the main points of the argument.

**Summary.** Given its reliability, validity and popularity, the FCI was chosen as the assessment tool for this project. There is also a significant amount of published data that uses the same test, so results from this study can easily be compared to previous research.
Educational Research on the Science Laboratory

Blosser (1983) surveyed research dealing with the role of the laboratory in science education. She states that the educational laboratory has been a common feature of introductory courses since the 1800s, and has received special emphasis during the reforms of the 1960s. According to Blosser, teaching laboratories are used to attain a wide variety of objectives, beyond merely acquiring content. These include attitudinal goals, familiarity with tools and techniques, and adding reality to the material in the textbook. The educational laboratory also has had its detractors, who feel that laboratory exercises may not present a clear picture of how real science is conducted (Blosser, 1983).

In Blosser’s opinion, much of the literature dealing with educational laboratories express opinions rather than research-based facts. She feels that too many of the research studies are doctoral dissertations that represent an individual’s first attempt at research, and do not include any follow-up studies. Many of the studies failed to detect statistically significant differences between educational treatments.

On a positive note, Blosser cites several studies that clearly demonstrate the effectiveness of laboratory activities, including a study by Comber and Keeves (1978) that compared science education in 19 countries, and found higher achievement levels in countries that made use of teaching laboratories.

Physics Education Research Laboratory Perspectives

In the context of the modern physics education research framework, several papers have investigated the effect of laboratory work on student learning.
**Thornton and Sokoloff’s First Paper.** Thornton & Sokoloff described a kinematics curriculum that was implemented with early MBL devices (Thornton & Sokoloff, 1990). Making use of a pretest/posttest design, they demonstrated the effectiveness of MBL-aided laboratory exercises. They concluded that MBL tools by themselves did not necessarily produce conceptual understanding, but that “These gains in learning physics concepts appear to be produced by the combination of the tools and the appropriate curricular materials.” (p. 865)

**Redish, Saul, and Steinberg’s Paper.** A study at the University of Maryland (Redish et al., 1997) attempted to extend the work of Thornton and Sokoloff by using MBL activities, controlling the time spent on the topic and probing the problem-solving ability of the students in the study. Engineering students in an introductory physics course were divided into two groups. One group of five lecture classes participated in recitations while the other group of five lecture classes participated in two MBL “tutorials” dealing with the concept of instantaneous velocity and Newton’s third law. Students were evaluated using the multiple-choice velocity questions developed by Thornton and Sokoloff, the FCI, and one long-answer question.

Although the treatment group only participated in tutorials dealing with instantaneous velocity and Newton’s third law, the whole FCI was administered in a pretest/posttest format to “provide a normalization of the overall effectiveness of the tutorial environment for general concept building.” (p. 48) It was found that the tutorial classes experienced greater normalized gains on the FCI, with $h = 0.35$, compared to $h = 0.18$ for the recitation classes. The results using Thornton and Sokoloff’s questions were consistent with their 1990 report, even controlling for the time spent by the two groups.
Redish et. al. concluded that MBL activities play a significant role in velocity concept formation.

The researchers further broke down their assessment by concentrating on the four questions on the FCI that deal with Newton’s third law, and calculating normalized gains for these questions. Results were tabulated for four MBL classes and six non-MBL classes (one of the classes used tutorials, but not the MBL ones). The normalized gains for the MBL classes were $h = 0.64$ and the non-MBL classes achieved $h = 0.28$.

**RQ1 in the Literature.** Redish et. al. reach a conclusion that “MBL tutorials can be effective in helping students build conceptual understanding, but do not provide a complete solution to the problem of building a robust and functional knowledge for many students.” (p. 52) At the end of the paper they state that

The Thornton-Sokoloff conjectures appear to be confirmed by a variety of anecdotes describing the success of the substitution of active-engagement MBL activities for traditional labs, and by the failure of the same equipment when used as traditional labs without the engagement/discovery component. These have not, unfortunately, been documented in the literature. It would be useful to have additional detailed experiments confirming different methods in order to build an understanding of exactly what components of MBL activities are proving effective. (p. 52)

It is to be noted that the substitution of MBL activities for traditional labs are described only anecdotally, which argues for the importance of a quantitative study.
Thornton and Sokoloff’s Second Paper. Thornton and Sokoloff (1998) evaluated the effectiveness of an instructional program that included MBL laboratories. This paper was devoted mostly to the development of a conceptual evaluation instrument called the Force and Motion Conceptual Evaluation (FMCE). This 43-question instrument bears some resemblance to the FCI, but contains a heavier emphasis on motion graphs.

In this project, data were collected from students enrolled at the University of Oregon and at Tufts University. Only about half of the students at Oregon enroll in a laboratory, which provided the researchers with treatment and control groups. In addition to the MBL labs, students also participated in Interactive Laboratory Demonstrations (ILDs) (Sokoloff & Thornton, 1997). Assessments were delivered before instruction, after traditional instruction, after ILDs, and on the final. Students who participated in labs were shown to achieve greater gains than those who did not. But since this study did not focus on the effects of the MBL labs by themselves, laboratory effects were de-emphasized when results were reported.

Sokoloff, Thornton & Laws provide online evidence of the effectiveness of their Workshop Physics program, of which RealTime Physics and ILDs are a part (Workshop Physics project, 2001). At the referenced website, bar-graph data is presented for students who have taken the FMCE as a pretest, after lectures, and after Workshop Physics. In the kinematics graphs section, the group describes the importance of the special homework and pre-lab discussions in producing large conceptual learning gains. In the dynamics section, the importance of observing real-time impulse curves is stressed.

Other Physics Laboratory Studies. Svec (1995) looked at two groups of introductory undergraduate physics classes, one of which used MBL laboratories with the
other using traditional motion labs. The two groups were enrolled in different courses, with the treatment group enrolled in Physical Science for Elementary Teachers and the control group taking General Physics. The specific nature of the laboratory procedures used for each group was not described. Effects were measured with an instrument developed for the study, which included questions taken from several conceptual exams, including the FCI. The treatment group showed greater gains than the control group, particularly in their understanding of motion graphs.

In an unpublished dissertation titled *Comparing the Effects of Different Laboratory Approaches in Bringing About a Conceptual Change in the Understanding of Physics by University Students*, Veath (1988) conducted a study similar to the present study. She assigned three laboratory sections of students taking an introductory physics course to one of three treatment groups: traditional, intermediate, and “prediction-modified learning cycle.” Veath found significantly greater conceptual learning gains for the prediction-modified group, compared to the other two. This study was conducted before the development of the FCI, and the nature of the conceptual testing instrument is unknown.

**Cookbook Labs and Inquiry Learning**

One can find many references to cookbook labs in the science education literature. The word appears in many article titles in recent years, including *A Cure for Cookbook Laboratories* (Lochhead & Collura, 1981), *Decookbook It!* (Shiland, 1997), and *A Recipe for Uncookbooking Laboratory Investigations* (Leonard, 1991). In these and many other articles teachers are advised to “throw out the instructions” (Tinnesand & Chan, 1987), and let students devise their own method to solve problems posed by the
teacher. From a constructivist viewpoint, Pushkin (1997) gives many examples of inquiry-style questions that can be integrated into physics laboratory exercises, and asserts that lab activities provide excellent opportunities to contemplate unfamiliar concepts. He argues that “when students are regimented by lab manuals that dictate what to think, how to think, and when to think, lab activities essentially lose impact for learning.” (p. 240)

Inquiry in the National Standards. Authors have often cited the need to bring laboratory exercises more into line with national education standards documents as a reason for “uncookbooking” laboratories. These sentiments are quite evident in this passage from The Liberal Art of Science (1990), published by the American Association for the Advancement of Science, as quoted by Leonard (1991):

Thus, use of the confirmatory approach in the laboratory and in the field does not contribute to the development of strong conceptual links between the natural world and the scientific theories developed to explain and predict it. Nor does this practice leave students with an accurate view of the practice of science. Rather, it contributes to the notion that the purpose of experimentation is the verification of hypotheses rather than their refutation.

Maximum benefit can be derived from laboratory and field experiences by having students work in groups and share their ideas, perceptions, and conceptions. Group design and interpretation of laboratory work are also effective strategies for exposing the changing misconceptions. In addition, students should prepare written reports describing the rationale for the experimental design, the data, and their interpretations. (p. 87)
This passage serves well as a definition of the components of an inquiry-based laboratory, from the perspective of the broad science education community. However, one can also distinguish from “open inquiry” activities as described above, and “guided inquiry.” In guided inquiry activities, the instructor has more control over the nature of the questions and methods of investigation than in open inquiry. MBL curricula, such as RealTime Physics (Sokoloff et al., 1999), used with the treatment group in this study, generally contain guided inquiry activities. These activities contain a large number of specific directions for the student, interspersed with reflective questioning to engage the learner. Students are thereby unable to “coast through” an interactive-engagement lab because they are actively engaged in thinking, even while receiving a large amount of direction.

**Definition of Interactive-Engagement Laboratories.** The preceding discussion motivates the following definition for “interactive-engagement laboratories,” for the purposes of this study: “Laboratory procedures that actively engage the learner by the use of pertinent questions integrated into the procedure, cooperative MBL activities, and an emphasis on concept formation.”

**Cookbook Labs Defined**

Leonard (1991) provides a description of a cookbook laboratory exercise when he writes

This student [previously described] is the victim of the overly prescriptive laboratory investigation, typical of those used in college introductory science courses. Such laboratory experiences tend to begin with the instructor explaining to the students, often in some detail, what will happen during the exercise in an
attempt to make certain that the student will carry out the exercise “correctly.”

The student is then left to follow a lengthy and detailed procedure in the 
laboratory textbook, which will occasionally call for responses such as describing 
what happens with the apparatus, making a drawing, or answering a specific 
question in the spaces provided in the manual. The entire procedure is very 
prescribed, that is, the student is told what to do in a step-by-step fashion for the 
entire exercise. (p. 84)

In a similar vein, Grote (1998) writes “Students can usually complete so-called 
‘cookbook labs’ with no understanding of what they did. Frequently, they do not form a 
complete picture of what happened because they focus on each step independently of the 
others.”

Though it is not necessary to travel back so far in history to find an example, a 
physics laboratory manual from the first quarter of the last century (Millikan, Gale, & 
Davis, 1925) illustrates a cookbook approach. In each experiment, an apparatus is 
described and diagrammed, and directions are given for the experiment. After these 
instructions, there is often a table provided for recording data. Several questions appear 
at the end of each experiment. This format is familiar to most of today’s scientists and 
educators because it is the one they used in their schooling. Examples abound throughout 
the last century, even into the last decade (Zitzewitz & Kramer, 1992). Given their 
historical prevalence, it seems likely that even today they are used in many educational 
physics laboratories.

**Definition of Cookbook Laboratories.** Given this background, in this study 
“Cookbook Laboratories” will be defined as “Laboratory procedures that follow a
‘cookbook’ approach, providing detailed instructions with no reflective questions integrated into the experimental procedure, ‘fill-in-the-blank’ data tables, and specific questions that occur after the exercise is completed.”

**MBL in Hake’s Study**

In Hake’s large 1998 study discussed previously, the 62 introductory physics courses were divided into “traditional” and “interactive-engagement” groups based on several criteria. Hake (1998b) identified seven different interactive-engagement instructional strategies, these being

1. Collaborative Peer Instruction (Mazur, 1997)
2. MBLs
3. ConceptTests (Mazur, 1997)
4. Overview Case Studies and Active Learning Problem Sets (Van Heuvelen, 1991)
5. Modeling Instruction (Wells, Hestenes & Swackhamer, 1995)
7. Other (p. 9)

Hake identified 22 separate strategies that he included in the “other” category. Each interactive-engagement course used at least two and usually more of the seven methods. Twenty-one of the 48 interactive-engagement courses used MBLs, and three of the fourteen traditional courses used MBLs. While Hake’s study clearly identifies a number of effective conceptual learning strategies, the effect of MBLs was not isolated, nor were the engagement levels of the experimental procedures identified.
Hake’s Case Studies and RQ2. In the unpublished addendum to his study, Hake (1998b) describes three case studies in which MBL labs were “grafted” onto otherwise traditional courses. Average normalized FCI gains for these three courses were only 0.26, 0.25, and 0.25. These results are close to the average gain for traditional instruction, 0.23. Hake cites several problems that may have occurred with the implementation of the MBL exercises in these low-gain courses. However, courses in the same situation at the University of Oregon and Tufts University produced very large knowledge gains, as measured by the FMCE. This discrepancy led Hake to encourage investigation of the following research question: “Can Grafting of IE Laboratories Onto Traditional Courses Markedly Increase Conceptual Understanding?” (p. 28). This question is restated as Research Question #2 (RQ2).

Student Satisfaction Surveys

Existing educational research regarding the usefulness of student satisfaction data is voluminous and complex. A broad spectrum of opinion exists as to the utility of such information, from “reliable, valid, and useful” to “unreliable, invalid, and useless.” (Aleamoni, 1981; quoted in Marsh, 1984, p. 708)

Even given this controversy, many researchers adopt an intermediate posture, and are interested in student satisfaction survey data whatever their worth may be (Greenwald & Gillmore, 1997). It is possible to embrace a position where student feedback is gathered in order to improve instruction, rather than merely using it to evaluate the teacher, its most common use (Bailey, 1983).
RQ3 was formulated in this moderate and constructive spirit. Its intent was to guide the collection of comparison data in order to provide information that supplements the main goals of the study as specified in RQ1 and RQ2.
CHAPTER III
METHODS

Population and Sample

The population for this sample was undergraduate students enrolled in an introductory physics course. This population was restricted to a sample of 52 students, who enrolled in a trigonometry-based introductory course at a small private Midwestern liberal arts college during the Spring and Fall terms of 2001. Phase I (Spring) enrollment was 25 and Phase II (Fall) enrollment was 27.

The sample included 27 males and 25 females. Their year in school and majors are summarized in Figure 3.1.

![Pie charts summarizing year in school and majors](image)

Figure 3.1. Pie charts that summarize the year in school and majors for participants in the study ($N = 52$).

Variables and Measures

Conceptual mechanics knowledge was measured for each subject using the Force Concept Inventory. The instrument was delivered as a pretest during the first few days of class, and as a posttest on the week after all lab exercises were completed. Students were told that posttest scores would be counted toward their grades.
Student satisfaction was measured with a Likert-style survey developed for this project (see Appendix A). The survey also solicited free-response feedback.

Limitations

1. The population of all students of college-level General Physics was limited to a sample consisting of students who enrolled in two course sections that were studied in this project. This sampling procedure limits the generalizability of the results.

2. The sample size was $N = 52$, which limits the statistical power of the experiment.

3. The treatment groups were determined by enrollment in one or the other of two sets of two laboratory sections. An attempt was made to obtain equal numbers of students in each group, to enhance the robustness of the statistical analysis. The use of this convenience sample makes this study a quasi-experiment, with attendant limitations in claimed causation.

4. This study was intended to be an equal-time experiment, with the two types of experimental groups spending equal amounts of time on each laboratory exercise, one two-hour lab period for each experiment. It is impossible for absolute equality to prevail, however, given the complexity of laboratory procedures and differences among students.

5. Students in the two laboratory sections attended the same lecture periods, three hours per week. In these lectures, the instructor did not make use of any reform-based instructional activities. He used a traditional lecture approach. Studies have shown (Hake, 1998a; Hake, 1998b) that this sort of instructional strategy tends to produce relatively small gains in conceptual mechanics knowledge. So
gains experienced by the treatment groups were expected to be smaller than they would be if MBL techniques were used in conjunction with other active-learning strategies. This limitation was accepted voluntarily, in order to isolate the effects due only to the MBL laboratory procedures.

6. Conceptual learning gains were compared by measuring the construct known as the “Newtonian force concept” for individual students. This conceptual construct is large and multi-dimensional, with attendant measurement difficulties. It was measured with the Force Concept Inventory (Hestenes et al., 1992). The construct validity of this test was considered in the Review of Literature.

**Procedural Steps**

This study was conducted using the following sequence:

1. The course instructor was asked to participate in the study.

2. IRB approval was obtained. All IRB documents appear in Appendix E.

3. Following a suggestion by the dissertation committee, a two-member advisory panel was retained to review the content and style of each cookbook lab.

4. On the first day of class in each phase, informed consent was obtained and the FCI was administered to all students.

5. Cookbook-style laboratory exercises were written for the cookbook group and reviewed by the advisory panel. These exercises appear in Appendix B.

6. During the first nine weeks of the Spring Term of 2000, the Phase I IE group participated in interactive-engagement laboratory exercises and the Phase I cookbook group participated in cookbook laboratory exercises.
7. In the week that followed completion of the last lab, all participants in Phase I took the FCI and the satisfaction survey.

8. The experiment was repeated during the Fall Term of 2001, with neither group in Phase II participating in post-lab homework assignments.

9. After the completion of Phase II, the instructor provided written feedback about the study (See Appendix D).

Treatments

The two laboratory sections in both Phase I and Phase II experienced two different levels of engagement in their MBL laboratory procedures. One group participated in interactive-engagement exercises, which in this experiment were defined as “Laboratory procedures that actively engage the learner by the use of pertinent questions integrated into the procedure, cooperative MBL activities, and an emphasis on concept formation.” The other group participated in cookbook exercises defined as “Laboratory procedures that follow a ‘cookbook’ approach, providing detailed instructions with no reflective questions integrated into the experimental procedure, ‘fill-in-the-blank’ data tables, and specific questions that occur after the exercise is completed.”

Both treatment groups participated in the same lecture section, which met three times a week. The instructor avoided interactive-engagement activities other than MBL laboratories, in order to isolate the effect of each treatment. The same instructor taught the lecture and both lab sections.

Each phase of the experiment lasted for ten weeks. Hake compared gain data for courses at six different institutions, in which the fraction of time spent on mechanics
instruction compared to a whole term ranged from 0.6 at Harvard to two courses that spent the whole term learning mechanics (Hake, 1998a). Hake found no large differences in conceptual gains, and argued that the gain difference is robust with respect to the amount of course time spent on mechanics. The introductory physics course in this study covered mechanics for approximately 87% of the course. This duration of treatment falls within those reported by Hake.

**Weekly Schedule.** During the treatment period in each phase, the interactive-engagement group participated in the following exercises from the laboratory manual *RealTime Physics: Mechanics:*

<table>
<thead>
<tr>
<th>Week</th>
<th>Chapter</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Introduction to Motion</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Changing Motion</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Force and Motion</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Combining Forces</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Force, Mass, and Acceleration</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Gravitational Forces</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Passive Forces and Newton’s Laws</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Newton’s Third Law and Conservation of Momentum</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>Two-Dimensional Motion (Projectile Motion)</td>
</tr>
</tbody>
</table>

Table 3.1. Exercises in *RealTime Physics: Mechanics* completed by the interactive-engagement laboratory section.

**Selection of Chapters.** The mechanics module of *RealTime Physics* contains 12 exercises. The nine chosen above were selected for their relevance to the FCI. Omitting three activities also helped accommodate the instructor’s normal class schedule.

Activities not included in this project were Lab 8: One-Dimensional Collisions; Lab 11: Work and Energy; and Lab 12: Conservation of Energy. Since the FCI does not include questions about momentum and energy, which are the main topics covered in Labs 8, 11,
and 12, it was reasonable to expect that these three labs would not contribute to conceptual gains measured by that instrument.

**Conduct of the Laboratory Activities.** Each experiment in *RealTime Physics* has been designed to last for two hours, if no extensions are used (Sokoloff et al., 1999). Extensions were therefore omitted in order to limit time on task to two hours for each exercise. Students who did not finish exercises in two hours turned in partially completed exercises in both sections. Students in the cookbook groups were instructed to begin working on the post-lab questions when there were fifteen minutes left in the lab period.

Students worked in groups of three or two for both sections. This is consistent with the recommendations of the authors, who suggest using groups of two to four students (Sokoloff et al., 1999). Every section of each *RealTime Physics* lab exercise was completed exactly as written (minus the Extensions). Adequate MBL equipment allowed faithful execution of all activities.

Each experiment in *RealTime Physics* includes a pre-lab exercise to familiarize the students with the activity and post-lab homework that reinforces that activity’s conceptual material. The authors stress the importance of completing these activities in order to achieve high conceptual gains. They were therefore included with the laboratory exercises in this study during Phase I. The pre-lab assignments completed by the cookbook groups were written to correspond with the activities that take place in the cookbook labs and are included with the Cookbook Labs in Appendix B.
During Phase II, neither group participated in the post-lab homework, in order to provide a varied comparison set. Both groups in Phase II also completed the pre-lab exercises.

The Student Satisfaction Survey.

Given the uncertainty surrounding student satisfaction surveys, no statistical hypothesis tests were performed with satisfaction data in this study. Any such quantitative analysis will be considered to be beyond the scope of this project. Student satisfaction responses will rather be presented only as supporting information for the reader, in tabular and graphical format.

The student satisfaction survey was developed specifically for this project, using some of the suggestions of Bailey (1983), and appears in Appendix A. Upon completion of Phase II, the course instructor provided written feedback about the project, which can be found in Appendix D.

Instructor and Lab Assistants.

The instructor in this project had been teaching introductory physics for about ten years. His normal style of teaching would be described as “traditional,” and he did not try to teach any differently during the study. He was somewhat familiar with the FCI, but was mostly unfamiliar with interactive-engagement instructional methods.

During each exercise, the instructor and a lab assistant were available to help the students complete the instructional activities. During Phase I the same lab assistant was assigned to both groups, and there were two different lab assistants for Phase II. The instructor and lab assistants did not make any special effort to teach mechanical concepts during the exercises through dialogue or questioning. This posture was adopted in order
to let the written instructions in the activities speak for themselves and avoid differences that could have existed between lab assistants. This was also meant to simulate implementation of the IE activities in RealTime Physics at a school where an instructor might not be present during the lab period, or where facilitators who are unfamiliar with IE teaching methods would simply provide the instructional materials to the students. This protocol was followed closely in Phase I, but was not implemented as strictly during Phase II. During Phase II, the instructor explained that he found it very difficult to avoid instruction during the labs and did more teaching during the exercises than in Phase I.

During Phase I the instructor graded all post-lab homework and included written comments. The homework was returned to the students before the next week’s lab session. Exercises were graded and returned before the next week’s lab for all four groups.

Writing the Cookbook Labs.

The two members of the Advisory Panel both had a great deal of experience writing and conducting MBL mechanics labs on the postsecondary level. While serving on the advisory panel, one member was the laboratory manager for the department of physics and astronomy at a large university. She was also a research associate in the physics education research group at that university. The other panel member was a graduate student in the same physics education research group and a former high school physics teacher.

The Advisory Panel was provided with a set of instructions, which can be found in Appendix C. After reviewing the instructions, one panel member provided this helpful list of characteristics for the two types of labs (Plano Clark, 2001):
**IE Group**
1. Use of prediction questions before data collection.
2. Analysis questions throughout activities, found near descriptions of the procedures.
3. Use of MBL.
4. Emphasis on the process.
5. Emphasis on conceptual understanding.
7. Higher-order reasoning - questions asking students to compare, contrast, synthesize, and evaluate.
8. Crucial interaction between students, materials, and instructor during lab.

**Cookbook Group**
1. No prediction questions.
2. Summary questions after activities completed, separate from write-up.
3. Use of MBL.
4. Emphasis on results.
5. Emphasis on formal equations.
7. Lower-order reasoning - questions asking students to give facts, summarize results, and apply knowledge.
8. Interaction only between students and materials.

These lists were adopted as an amplification of the definitions, and applied to the writing of Labs #2-9. Of course, the IE labs for this project were already in existence, so the IE list did not guide their writing, but provided contrast for the cookbook list. Item #8 in the IE Group characteristics would normally apply, but the level of interaction between instructor and students during the labs was held fixed between the two groups as discussed above.

With this complete set of guidelines in place, each lab exercise went through a feedback cycle of suggestions from the Review Panel and revisions. Each cookbook lab was given the same title as its counterpart IE lab. The final versions of the cookbook labs that appear in Appendix B were then completed by the students in the Phase I and Phase II cookbook groups.
Given that no available cookbook MBL lab activities were found in published form, the cookbook labs were written “from scratch.” Some of the lab activities were modifications of procedures that had been previously used by the researcher while teaching the course. Each lab was meant to cover the same concepts as the labs in RealTime Physics, and many of the activities in the cookbook labs are similar to those in RealTime Physics, but written in “recipe” style. A few of the procedures and all of the graphics were taken from Physics Labs with Computers, Volume 1, published by PASCO scientific (1996), which is the activity guide one receives from PASCO when purchasing their MBL equipment sets.
CHAPTER IV
RESULTS

The Hake Factor

Following Hake (1998a), average normalized gains (commonly referred to as the Hake Factor, $h$) on the FCI were calculated for individuals using the formula

$$h = \frac{\text{post} - \text{pre}}{1 - \text{pre}}.$$  These individual gains are displayed on a Hake Plot in the Figure 4.1.

Figure 4.1. Hake Plot for individuals ($N = 52$) in each treatment group. Phase I included homework, Phase II did not.
Average Normalized Gains

To assess the effectiveness of the instructional treatment for each of the four experimental groups, average normalized gains were calculated for each group. The average gains are reported in Table 4.1, along with average pretest and posttest scores.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Pre</th>
<th>Post</th>
<th>h</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cookbook I (with HW)</td>
<td>11</td>
<td>0.303</td>
<td>0.570</td>
<td>0.392</td>
<td>0.174</td>
</tr>
<tr>
<td>IE I (with HW)</td>
<td>14</td>
<td>0.298</td>
<td>0.621</td>
<td>0.471</td>
<td>0.201</td>
</tr>
<tr>
<td>Cookbook II (no HW)</td>
<td>14</td>
<td>0.343</td>
<td>0.548</td>
<td>0.334</td>
<td>0.257</td>
</tr>
<tr>
<td>IE II (no HW)</td>
<td>13</td>
<td>0.338</td>
<td>0.646</td>
<td>0.480</td>
<td>0.257</td>
</tr>
</tbody>
</table>

Table 4.1: Summary of pretest scores, posttest scores, and mean normalized gains for the four experimental groups.

![Figure 4.2](image)

In performing the calculations above, one individual was excluded from the IE I group. This subject withdrew from the course the same week that she took the posttest FCI, and actually scored lower on the posttest than the pretest (pre = 10 correct, post = 7 correct). The instructor felt that this student was probably not taking the test very
seriously since she knew she would be immediately withdrawing from the course. This was also the only individual to show negative gain on the FCI. If this score is included in the group, the average gain for IE I becomes 0.430.

Figure 4.3 shows the Hake plot for the group averages.

Figure 4.3. Hake plot for group averages. The two dashed lines divide the allowable region into areas of high-gain, medium-gain, and low-gain. The two thin solid lines show the average normalized gains for the 14 traditional courses and the 48 IE courses in Hake’s study, which are included in the plot.

Hake (1998a) noted that the absolute value of the slope of a line connecting any point with the point (1,0) in the lower right-hand corner of the plot is equal to the normalized gain for that point. The plot can therefore be divided into three regions that
correspond to high-gain courses \((h \geq 0.7)\), medium-gain courses \((0.7 > h \geq 0.3)\), and low-gain courses \((h < 0.3)\). Two thin solid lines are also plotted that show the value of the average gains for the 14 Traditional and 48 IE groups in Hake’s data set, 0.23 and 0.48. These courses are also included in the plot. In Hake’s study, all 14 Traditional courses fell in the low-gain region. In the present study all four groups are in the medium-gain region, with the Cookbook II group near the low-gain borderline.

**T-Test Results**

Unpaired one-tail \(t\)-tests were performed on the two pairs of groups to determine if differences in mean gain scores were statistically significant. The results are presented in Table 4.2.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Mean Difference</th>
<th>Degrees of Freedom</th>
<th>(t)-Value</th>
<th>(p)-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0.079</td>
<td>23</td>
<td>1.036</td>
<td>0.1556</td>
</tr>
<tr>
<td>II</td>
<td>0.146</td>
<td>25</td>
<td>1.478</td>
<td>0.0760</td>
</tr>
</tbody>
</table>

Table 4.2. Results of unpaired \(t\)-tests between the IE and cookbook groups in both phases of the experiment.

Neither of the differences were significant at the 5% level \((p > 0.05)\), though the results in Phase II are significant at the 10% level \((p < 0.10)\).

**Student Satisfaction Survey**

The student satisfaction survey appears in Appendix A. For purposes of reporting, the following abbreviations will be used.
Table 4.3. Abbreviations used for reporting satisfaction survey results.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>It was difficult to complete the lab exercises in the allotted time.</td>
</tr>
<tr>
<td>Interesting</td>
<td>My lab experiences have been very interesting.</td>
</tr>
<tr>
<td>Challenging</td>
<td>I had to work hard during the lab exercises.</td>
</tr>
<tr>
<td>Worthwhile</td>
<td>The pre-lab exercises were worthless.</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>I enjoyed the lab exercises.</td>
</tr>
<tr>
<td>Understandability</td>
<td>It was difficult to understand what the lab procedures told me to do.</td>
</tr>
<tr>
<td>Importance</td>
<td>The lab activities are the least important part of this course.</td>
</tr>
<tr>
<td>Learning</td>
<td>I learned a lot from the lab exercises.</td>
</tr>
<tr>
<td>Equipment</td>
<td>I enjoyed working with the computer-interfaced lab equipment.</td>
</tr>
<tr>
<td>Learn Physics</td>
<td>The lab procedures helped me learn physics.</td>
</tr>
<tr>
<td>Partners</td>
<td>The lab procedures made it difficult for me to work with my partners.</td>
</tr>
<tr>
<td>Thinking</td>
<td>The lab procedures made me think.</td>
</tr>
<tr>
<td>Homework</td>
<td>The post-lab homework was valuable.</td>
</tr>
</tbody>
</table>

To generate the averages in Table 4.4, responses were adjusted so that a higher score corresponds to a positive response. In other words, a high score indicates agreement with a positive question and disagreement with a negative question. Each question ranges from 1 (very negative) to 5 (very positive). Pooled standard deviations for each question are included.

Table 4.4. Average response scores to the Student Satisfaction Survey for the four experimental groups. High scores correspond to positive responses.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Cookbook I</th>
<th>IE I</th>
<th>Cookbook II</th>
<th>IE II</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>2.000</td>
<td>2.714</td>
<td>2.615</td>
<td>2.615</td>
<td>1.255</td>
</tr>
<tr>
<td>Interesting</td>
<td>3.818</td>
<td>3.286</td>
<td>4.143</td>
<td>3.923</td>
<td>0.848</td>
</tr>
<tr>
<td>Challenging</td>
<td>3.636</td>
<td>3.071</td>
<td>3.357</td>
<td>3.923</td>
<td>1.019</td>
</tr>
<tr>
<td>Worthwhile</td>
<td>2.818</td>
<td>2.643</td>
<td>3.500</td>
<td>2.846</td>
<td>1.102</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.818</td>
<td>3.714</td>
<td>3.923</td>
<td>3.692</td>
<td>0.673</td>
</tr>
<tr>
<td>Understandability</td>
<td>3.091</td>
<td>3.714</td>
<td>4.071</td>
<td>3.385</td>
<td>0.934</td>
</tr>
<tr>
<td>Importance</td>
<td>3.909</td>
<td>3.769</td>
<td>3.929</td>
<td>3.615</td>
<td>0.849</td>
</tr>
<tr>
<td>Learning</td>
<td>3.364</td>
<td>3.643</td>
<td>3.643</td>
<td>3.769</td>
<td>0.911</td>
</tr>
<tr>
<td>Equipment</td>
<td>3.636</td>
<td>3.643</td>
<td>3.929</td>
<td>3.769</td>
<td>0.883</td>
</tr>
<tr>
<td>Learn Physics</td>
<td>3.636</td>
<td>4.000</td>
<td>3.786</td>
<td>3.615</td>
<td>0.807</td>
</tr>
<tr>
<td>Partners</td>
<td>3.818</td>
<td>3.929</td>
<td>4.357</td>
<td>3.923</td>
<td>0.804</td>
</tr>
<tr>
<td>Thinking</td>
<td>3.909</td>
<td>3.929</td>
<td>3.857</td>
<td>4.077</td>
<td>0.850</td>
</tr>
<tr>
<td>Homework</td>
<td>2.909</td>
<td>2.929</td>
<td>NA</td>
<td>NA</td>
<td>1.038</td>
</tr>
</tbody>
</table>

Figure 4.4 presents average responses for the four groups graphically.
Figure 4.4. Bar graph of satisfaction survey responses by treatment group.

Figure 4.5 shows responses to the survey split by the type of group, IE or cookbook.
Figure 4.5. Bar graph of satisfaction survey responses by type of treatment group.

Figure 4.6 shows responses to the survey split by term, i.e. whether or not the participants also did the homework.
Figure 4.6. Bar graph of satisfaction survey responses by term, i.e. whether or not the participants also did the homework.

The opinion survey also included three free-response questions. Student responses are summarized in the following 3 tables.
Do you have any suggestions that would improve our Phys-111 labs?

<table>
<thead>
<tr>
<th>Suggestions</th>
<th>Cook I</th>
<th>IE I</th>
<th>Cook II</th>
<th>IE II</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Make them shorter</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Include better instructions</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Allow us to have the labs when we do the HW</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use activities that are less similar</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Include more real-life applications</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make the labs coincide better with regular class</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make instructions less succinct/redundant</td>
<td></td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Make less reliant on computers</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Make less mathematical</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Don’t use this book</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Make the pre-lab questions easier</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use more diagrams</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.5. Summary of student responses to the first free-response question on the opinion survey.

What has been your favorite part of Phys-111 labs so far?

<table>
<thead>
<tr>
<th>Favorite Part</th>
<th>Cook I</th>
<th>IE I</th>
<th>Cook II</th>
<th>IE II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowling ball lab</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projectile lab</td>
<td>4</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working with computer</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>The experiments</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Fan carts</td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Skateboard lab</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working with people</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The graphs</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hands-on activities</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Using a varied approach</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tracks and carts</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy grade</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equations</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good instructions</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.6. Summary of student responses to the second free-response question on the opinion survey.
<table>
<thead>
<tr>
<th>What has been your least favorite part of Phys-111 labs so far?</th>
<th>Cook I</th>
<th>IE I</th>
<th>Cook II</th>
<th>IE II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Too long, not enough time</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>The homework</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-labs</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Computer malfunctions</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Velocity labs</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doing the labs</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not “real-life”</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The questions</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Wordy procedures</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor integration with class</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monotonous and repetitive</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Too complicated</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Motion labs</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Nothing</td>
<td></td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Plugging in numbers</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>My lab partner</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.7. Summary of student responses to the third free-response question on the opinion survey.
CHAPTER V
DISCUSSION

In this chapter, each of the research questions will be considered in order. They are re-listed below for convenience.

RQ1. Are there significant differences in the conceptual mechanics knowledge gain (as measured by the FCI) for students who participate in active-learning MBL physics laboratories, compared to students who participate in equal-time exercises with cookbook procedures that also make use of MBL equipment?

RQ2. Can the use of interactive-engagement laboratories in conjunction with an otherwise traditional classroom environment produce significant gains in conceptual learning?

RQ3. How do the satisfaction and perceived effectiveness of the exercises compare for students in the two groups?

Research Question #1

Data was collected in both phases of this project in order to statistically test the following null hypothesis:

\[ H_0: \text{Average normalized gains on the FCI for the IE group were not significantly higher than gains for the cookbook group.} \]

Neither Phase I nor Phase II displayed differences in average normalized gain scores on the FCI that are statistically significant at the 5% level, with \( p \)-values of 0.1556 and 0.0760, respectively, so the study failed to reject \( H_0 \). It is to be noted, however, that the Phase II data is very close to the significance threshold. A \( p \)-value gives the probability
of the group differences being due to chance, assuming the data is normally distributed. This means that there is a 7.6% probability of this difference occurring because of random effects. The standard deviations for the two groups in Phase II are equal, 0.257, which yields a medium effect size of 0.568 s.d.

A beta value ($\beta$) is the probability of committing a Type II error, which is incorrectly failing to reject the null hypothesis. In Phase II, the beta value is equal to $\beta = 0.5912$ at the $\alpha = 0.05$ level, and $\beta = 0.4376$ for $\alpha = 0.10$. The statistical power, $P = 1 - \beta$, is the probability of properly rejecting a false null hypothesis. The corresponding power values for $\alpha = 0.05$ and $\alpha = 0.10$ are $P = 0.4088$ and $P = 0.5624$, respectively. Lipsey (1990) has shown that $P$-values in social science experiments tend to average about 0.45.

In Hake’s study (1998a), which collected data for over 6000 students, the standard deviation for the gain scores with traditional instruction was equal to 0.14. The standard deviation for the IE group was 0.04. The standard deviation for gain scores in Phase II of this study was 0.257, which indicates quite a bit more variation than Hake’s data. This variation had a negative impact on the $p$-value in the Phase II $t$-test. If, for instance, the standard deviations for the two groups had been 0.22 instead of 0.257, the $p$-value would have been 0.048.

The $p$-value in Phase II was also hurt by the small $N$ in this study. An effect size of 0.568 s.d. would have been statistically significant ($p = 0.049$) if the $N$ for both groups had been 18, rather than 14 and 13.

The differences between groups were smaller in Phase I of the study. This may be due to the fact that the cookbook group completed the homework problems in the
RealTime Physics exercises. Perhaps the similarity between this homework and the conceptual questions on the FCI had a positive effect on gain scores for the cookbook group. Regardless of the reason for the difference, Phase II provided a more accurate comparison between active-learning and cookbook laboratory procedures, since one would not usually expect a traditional lab to include a conceptual homework component.

This study was not undertaken to investigate the effect of using conceptual homework in conjunction with laboratory exercises. It is interesting to note, however, that the added homework did not seem to have an effect on the performance of the IE groups, while it did help the cookbook groups.

It may have been more desirable to make a direct single-term comparison of an IE group that did the homework and a cookbook group that did not, since this more accurately represents typical classroom implementation of these treatments.

Given this discussion, it seems appropriate to argue that the answer to RQ1 is a qualified “yes.” The more relevant Phase II data skirts the threshold of statistical significance. This argument is made stronger by the tight controls established between the two groups. Students attended the same lectures, completed the same daily work, and spent the same amount of time in the laboratory (though it should be acknowledged that the instructor reported that he did more “teaching” during the labs in Phase II).

Are the Cookbook Labs Realistic? The validity of the results regarding RQ1 depend strongly upon the precise nature of the cookbook labs that were written for this study. Any weaknesses in these labs translate directly into a lack of generalizability of the results of this study. It is left to the reader to inspect the exercises and decide if they provide a genuine contrast to the engaging procedures found in RealTime Physics.
The cookbook labs are not the types of activities that one would expect a “real” traditional teacher to use in their educational laboratory. This is especially true since they closely follow the chapters in *RealTime Physics* in an attempt to provide equal content.

Several of the labs mirror the activities of the corresponding *RealTime Physics* chapter section by section, with the engaging portions of the activities (embedded questions, predictions, etc.) removed. By removing these engaging elements, the cookbook labs became shorter than their IE counterparts. To compensate for this, the cookbook labs included a stronger emphasis on calculations and sometimes repeated trials or used more variations in the experimental setup. Entirely different activities were undertaken in some of the labs, especially the last two.

Whether the labs followed the *RealTime Physics* activities or took a diverse approach to the material, the inclusion of activities depended upon the approval of the Review Panel. The nature of the labs, and whether or not they provided a true example of a cookbook lab, therefore relied on the collective opinion of the author and these two individuals.

**The Instructor’s Critique.** The instructor in this project provided feedback after the study was completed (Hermann, 2001). Regarding the IE labs, he said

As it was, the IE labs often felt like a set of rather unconnected experiences, which the students would hopefully put together into one conceptual framework. There was no well-defined beginning, middle and end; there were only as many experiences as the student could get through in two hours. The transitions between exercises within a lab made sense to me, but the students never noticed them and often asked about what they were doing and why.
The traditional labs also suffered from this problem, but even more so. Traditional labs usually have a beginning (deriving some equation, designing an experimental set-up, calibrating the instruments) a middle (taking data, analyzing it in graphs and/or equations, coming up with a result) and an end (calculating errors or uncertainties, writing conclusions). These traditional labs had no such parts. They were simply the IE labs without the connecting prose and questions, so there was even less to guide the student through the lab and show why they were doing what they were doing. In some cases this lack of excess verbiage actually helped the students see the “big picture” of what they were doing, but in my opinion it did not make these labs “traditional”. (p. 6)

“Traditional” vs. “Cookbook”. During the planning and implementation phases of this study, the treatment groups were labeled “IE” and “Traditional.” During the analysis phase it was decided that it would be more accurate to refer to the “Traditional” groups as “Cookbook” groups. The title of the project was also modified at this time. This decision was based largely upon the instructor’s opinion quoted above, and his comments are easier to understand if one realizes that the cookbook labs were referred to as “traditional” labs when he conducted them.

Length of Treatment. The length of the treatment in this study deviates from what one would consider “traditional.” Even reducing the twelve chapters in RealTime Physics to nine, more time may have been devoted to mechanical concepts than would be normal in a traditional course.

Given these shortcomings of verisimilitude, it should be acknowledged that RQ1 could have been answered more definitively if the quality of the cookbook labs had been
higher. In an ideal situation, the cookbook groups would have completed labs already in existence, in order to ensure comparison with a realistic alternative to RealTime Physics. Lacking this, these results should probably be considered to apply more to “cookbook” labs than to “traditional” labs, since physics educators would be likely to classify the non-IE labs in this study as the former even if not the latter.

**Research Question #2**

The average gain for the IE groups in Phase I and II were 0.471 and 0.480, so their pooled average gain was 0.476. The average gain for all IE groups in Hake’s study was 0.48. This similarity would seem to indicate that interactive-engagement laboratories in conjunction with an otherwise traditional classroom environment can produce gains in conceptual learning comparable to those in a classroom where the teacher uses interactive-engagement teaching methods.

This conclusion may be mitigated by the fact that the cookbook groups in this study also performed rather well. In making this comparison, it’s best to consider only the Cookbook II group, since their instructional treatment did not include the conceptual homework. Their average gain score was 0.334. This is greater than the average traditional gain in Hake’s data, 0.23. The conceptual mechanics knowledge gained by the students in the cookbook group in this particular class was above average, but the difference in the gain scores for the two Phase II groups also argues for a positive answer to RQ2.

As noted above, the duration of the treatment was probably longer than one would expect in a traditional course. The decision to graft such a long set of IE labs onto a
A traditional course would depend on the preferences of implementing instructors, and it should be noted that the results of this study were achieved with a nine week treatment.

Instructors who decide to graft an IE lab onto a traditional course might also encounter problems because their lecture topics are not synchronized with the laboratory exercises, as was the case in this project. The instructor spoke to these issues by saying:

To use the IE labs effectively, I think that the instructor needs to be able to vary the way time is spent in lab and in lecture. Instead of having one two-hour lab each week and three lectures, an effective use of time would be to spend one whole week doing several of the labs, and then a few weeks without doing any labs. As it is, if the lectures continue at their normal pace, the students are well past the concepts covered in many of the labs by the time that they do the lab, and the exercises seem like a tedious chore to develop something that the students are already familiar with. On the other hand, if the lectures keep pace with the labs, then the amount of material covered must change dramatically. It may be nice to spend three weeks developing Newton’s Second Law and over five weeks with forces, but this is at the expense of a good coverage of momentum, and all mention of rotations, torque, and oscillations. To say that IE labs do a great job of teaching forces is not really fair, since I could produce students expert at almost any topic if I spent five weeks on it. (Hermann, 2001, p. 6)

**Research Question #3**

While the application of statistical hypothesis testing to the Likert-style survey data in this study has been avoided, one can make several generalizations about the numerical responses to the questions, as displayed in Figures 4.4-4.6.
In Figure 4.5, responses are compared by group type, IE vs. cookbook. In the differences that exist, students responded more strongly in favor of the cookbook labs in questions having to do with personal preference, including Interesting, Worthwhile, Enjoyment, Understandability, and Importance. The IE labs were rated slightly better in questions having to do with perceived effectiveness, including Learning, Learn Physics, and Thinking. These differences may or may not be generalizable, but the pattern is evident.

When comparing the Phase I and Phase II responses in Figure 4.6, even larger differences are apparent. The students who did not do the homework problems responded more positively to the labs in every question except for Importance, Learn Physics, and Thinking (which was a tie).

Qualitative observations by the instructor seem to support the patterns described above. According to him, the students who did the cookbook labs seemed to be generally more satisfied with them, especially during Phase I. This may be due to the precision of the instructions associated with these labs, which allowed the students to “cruise through” the procedures, following the recipe to its conclusion. Perhaps the cookbook labs were easier to complete, and thus more popular.

The instructor further elaborated on the popularity of the labs, explaining that the IE labs were less popular “because students in the traditional labs could at least tell what concepts they were working on, even if they couldn’t finish the lab, while students in the IE labs often had no idea what they were doing or what they were supposed to get from the lab if they couldn’t finish it.” (Hermann, 2001, p. 6)
In an informal conversation after the project was completed, the lab assistant for the Cookbook II group expressed the opinion that the lower-achieving students in her group tended to be more satisfied with the cookbook labs. She noted that high-achieving students were often frustrated by the precise mechanical instructions but that students with little interest in physics appreciated them.

**Suggestions for Future Research**

It would be useful to repeat Phase II of this study with a larger sample size. If the differences between IE and cookbook groups would be persistent, the results would have more statistical significance.

It might also be interesting to look more closely at the relative importance of the conceptual homework that is included with the RealTime Physics exercises. The results of this study suggest that it has little effect on conceptual learning gains for students who complete IE lab exercises, but that it does have some benefit for students who do not. Is this due to the similarity between the homework and the questions on the FCI, or does it indicate a genuine shift in beliefs about mechanical concepts? Can students in a traditional course merely complete these homework sets to produce a measurable gain in FCI scores?

The cookbook labs in this project suffered from a lack of realism. Perhaps further research could make a comparison between IE labs and labs that would truly be considered “traditional.” Are there mechanics lab exercises in existence that would provide a more realistic contrast to the IE labs? Might there be other benefits to traditional labs that are not measured by the FCI, like the ability to make quantitative
calculations? This type of study may require the use of measurement instruments other than the FCI.

Perhaps a survey could be undertaken to determine the characteristics of labs that are currently being used by physics teachers. It would be interesting to find out how common cookbook labs are, and to ascertain the actual characteristics of traditional labs that are currently being used by physics teachers.

Further research could also be conducted to measure the attitudes of the students toward the two types of labs more extensively. It would be helpful to gather qualitative data to probe these attitudes. Could it be found that preferences for one type or the other correlate with other student attributes, like educational backgrounds, attitudes toward science, GPAs, or math skills? These preferences may help explain the persistence of traditional lab procedures in educational physics laboratories.
In his famous Nike commercial series, Spike Lee’s character Mars Blackmon watched Michael Jordan in action and asked the question “Is it the shoes?” Obviously, the shoes do not make the player, but better shoes can help basketball players perform better. With the proliferation of educational physics laboratory equipment available today, a physics teacher might likewise ask “Is it the gadgets?”

Merely using MBL gadgets in an educational physics laboratory doesn’t make students learn. The ubiquitous negative references to cookbook labs in the educational literature support the common-sense notion that mindless lab procedures are less likely to produce conceptual learning. By deliberately writing cookbook laboratory procedures and comparing them to interactive-engagement procedures, this study was undertaken to acquire quantitative data in support of this seemingly obvious idea.

The cookbook labs were written to be as error-free as possible. They contained accurate information and directed the students to perform activities that worked, made sense, and illustrated mechanical concepts. They were written rigorously, but in a way that deliberately failed to engage the student while the exercise was being undertaken and lacked embedded conceptual instruction.

In a tightly controlled setting, where students covered identical concepts, used identical equipment, attended identical lectures and spent an equal amount of time in both groups, the students who completed the more engaging labs achieved higher normalized gains on a pretest-posttest FCI exam. Under these circumstances, the engagement level
of the laboratory procedures produced a difference between groups of 0.568 standard deviations, a medium effect size.

Since the students in the interactive-engagement lab groups attended an otherwise traditional physics course, it can also be argued that it is possible to have students in a traditional course participate in an interactive-engagement lab section and attain respectable gains in conceptual mechanics knowledge. These students acquired an average normalized gain of 0.476, which compares favorably with reported gains utilizing more extensive treatment regimes.

Opinion data collected in this study seems to suggest that the cookbook labs were somewhat more popular with the students than the interactive-engagement labs. These differences were fairly small, and one could argue that they are offset by larger learning gains.

By providing a quantitative argument about the effectiveness of actively engaging procedures in the introductory physics laboratory this study provides individual physics instructors with more information with which to make decisions about the nature of the laboratory exercises they provide for their students. It’s not just the gadgets, it’s how you use them that counts.
REFERENCES


Greene, R. (2000, 10/30/00). Post to PHYS-LRNR Listserv. [Email].


Hake, R. (2000, 11/10/00). Post to PHYS-LRNR Listserv. [Email].


APPENDIX A

The Student Satisfaction Survey
Name ___________________________

**Student Laboratory Opinion Survey**

Please answer the following questions regarding your laboratory experience so far in Phys-111. Read each question carefully and circle the appropriate answer, using the following code:

5 = Strongly Agree  
4 = Agree  
3 = Not Sure/ I don't know  
2 = Disagree  
1 = Strongly Disagree

<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>It was difficult to complete the lab exercises in the allotted time.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>2</td>
<td>My lab experiences have been very interesting.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>3</td>
<td>I had to work hard during the lab exercises.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>4</td>
<td>The pre-lab exercises were worthless.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>5</td>
<td>I enjoyed the lab exercises.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>6</td>
<td>It was difficult to understand what the lab procedures told me to do.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>7</td>
<td>The lab activities are the least important part of this course.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>8</td>
<td>I learned a lot from the lab exercises.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>9</td>
<td>I enjoyed working with the computer-interfaced lab equipment.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>10</td>
<td>The lab procedures helped me learn physics.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>11</td>
<td>The lab procedures made it difficult for me to work with my partners.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>12</td>
<td>The lab procedures made me think.</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>13</td>
<td>The post-lab homework was valuable.</td>
<td>1 2 3 4 5</td>
</tr>
</tbody>
</table>

Do you have any suggestions that would improve our Phys-111 labs?

What has been your favorite part of Phys-111 labs so far?

What has been your least favorite part of Phys-111 labs so far?
APPENDIX B

Cookbook Lab Exercises
1. How many total velocity trials will be measured in *Part I*?

2. What type of probe will you plug into the interface box to make your velocity measurements in *Part I*?

3. What type of moving object will create the motion graphs in *Part II*.

4. What new type of graph will you investigate in *Part III*?

5. What two ways will you measure the speed of the coasting cart in *Part IV*?
**Lab 1: Introduction to Motion**

**Objective:** To practice techniques for measuring positions and velocities and become familiar with the interfaced lab equipment.

**Procedure**

**Part I: Constant Velocity Measurements with a Photogate**

1. Obtain a collision cart and place it on your track. Level your track. We wish to use a photogate to measure the speed of the cart. Set up the photogate so that the gate is blocked by the widest solid pattern on the five-pattern picket fence card. Plug the photogate into Digital Channel 1 on the *Science Workshop* interface box.
2. Run *Science Workshop* on your computer. On the computer screen, “drag” a digital plug onto the picture of Digital Channel 1 on your screen. Select *Photogate & Solid Object* on the next menu, and use a meter stick to measure the width of the wide pattern on the card. Enter this value as *Object Length*.
3. Display a table of velocity values as measured by the photogate. To do this, drag a new table onto channel one, select *Velocity, v, (m/s)*, and click <Display>. You are now ready to take measurements. Minimize the controller window and drag the table to the middle of the screen. If you click on **MON**, measurements will be taken, but not recorded. Try this now, pushing the track back and forth through the photogate a couple times to make sure measurements are being taken. When you press **REC**, the measurements will be “remembered” by the computer.
4. Press **REC** and push the cart so that it coasts through the photogate for ten trials. Make the cart move in the same direction each time and catch the cart with your hand. When ten numbers are displayed on the screen, click the sigma (\(\Sigma\)) symbol on the velocity table to display statistics. Record the ten measurements on your answer sheet, along with the mean and standard deviation for the data.
5. Do another ten trials, this time trying to make the velocities as nearly constant as possible. Record this new table in your notebook.
6. Do another ten trials this same way, but this time adjust the photogate so that it is blocked by the smallest pattern on the card. Make sure you reconfigure the software so that it knows that the blocking object is smaller. Record your data.

**Part II: Graph Matching**

1. Disconnect the photogates and put them away. Obtain a motion sensor and connect its stereo phone plugs to Digital Channels 1 and 2 on the interface. The yellow plug always goes in Channel 1.
2. Configure the *Science Workshop* software to display a position-time graph, as measured by the motion sensor. Close the velocity table you used in Part I. Drag a new digital plug onto Channel 1, and select *Motion Sensor*. Click <OK> at the next screen. Drag a new graph onto Channel 1, and select *Position, x, (m)*.
Minimize the controller window. Resize and reposition the graph window so that it takes up the rest of the screen.

3. Now you will be the object whose motion will be studied. Mount the motion sensor on a support rod so that it is aimed at your midsection when you are standing in front of it. Make sure you are able to move backwards at least 2 meters while seeing the computer monitor.

4. Click on the controller window to make it active. Make sure the switch on the motion sensor is set to its “wide beam” setting. Have someone move in front of the motion sensor after you click the MON button. You should see a graph of that person’s motion displayed. Click STOP. Then click on REC and have someone move while a five-second sample is taken. The computer will stop taking data when you click on STOP, and saves the run. Click on the Autoscale button: Note that you can highlight a run and delete it later.

5. Make two graphs, sketching them in the first two graphs on the answer sheet. First start 0.5 m from the sensor and walk away from the detector slowly and steadily. Then repeat, but walk away medium-fast and steady. Have someone click STOP at the appropriate time.

6. Do it twice more, but this time move toward the sensor. Sketch the graphs in the second pair of grids on the answer sheet.

7. While you take data, move in the following way: start 0.5 m away from the sensor, walking away from the detector very slowly and steadily for 5 s, stop for 2 s, then walk toward the detector twice as fast. Sketch the resulting graph on the answer sheet on the graph called Go Stop Go.

8. Try to move so that you match the two graphs below:

9. Quit Science Workshop. Open the Science Workshop file called Graph Match. It is found in the folder Lab 1 inside the folder Concordia Labs in the Phys-111 folder on your desktop. All configuration files you use in these labs will be inside the Concordia Labs folder.
10. Click on the Experiment Setup window to make it active. Click on the graph window and resize it to fill the screen, without covering the Experiment Controller window. Click on the Autoscale button.

11. Study the graph on the screen. Your goal is to move in a way that matches the graph. Note that clicking the MON button allows you to do a “dry run.” Monitor yourself a couple times, then when you are ready, click the REC button. Repeat the process at least two more times to try to improve the match. Figure out how to display any of the trials—alone or with others. (Science Workshop is able to display up to three data runs at one time.)

12. Each person in your group needs to take a turn being the “mover.” Each time a new person begins their turn, delete all the old data runs except a best run for each previous person.

13. When you have a best run for each person in your group, display all graphs. Print a graph for each group member, to be included with the answer sheet.

14. Now we will use the computer to determine the slope of a line. We will measure the slope for the middle section of the plots. Change your display so only one set of data is showing. Now click on the Statistics (Σ) button and then the Autoscale button to resize the graph to fit the data.

15. Click on the Statistics Menu (Σ) button. Select Curve Fit, Linear Fit from the menu. Next, use the cursor to click-and-draw a rectangle around the section of your plot you wish to analyze. Choose a smooth part of the upward-sloping section. If you don’t choose a good region, you can always re-select. Look at the best fit line that is drawn on the graph. Find the slope of the line. It is given as the number “a2.” Record this number on your printed graph.

Part III: Velocity Graphs

1. Quit Science Workshop. Run the program and configure it like you did in Part II, but this time display a velocity-time graph.

2. Make two graphs, sketching them in the first two v-t graphs on the answer sheet, which are labeled Away, Slow and Away, Medium-Fast. First start 0.5 m from the sensor and walk away from the detector slowly and steadily. Then repeat, but walk away medium-fast and steady. Have someone click STOP at the appropriate time.

3. Do it twice more, but this time move toward the sensor. Sketch the graphs in the grids labeled Toward, Slow and Toward, Medium-Fast.

4. For the next run, move in the following way: start 0.5 m away from the sensor. Walk away from the detector very slowly and steadily for 5 s, stop for 5 s, then walk toward the detector twice as fast. Sketch the result on the Go Stop Go grid.

Part IV: Constant Velocity Carts

1. From the file menu, select “New” to open a new experiment window (you don’t need to save changes to the old one). Configure the software to use a motion sensor as before. Create a graph window that displays both position and velocity. To do this, drag a new graph onto the motion sensor icon. Click on Position, x (m) and hold
down the <shift> key while you click on Velocity, \( v \) (m/s). Click <OK>. Minimize the Experiment Controller window, and resize the graph window so it takes up all of the remaining room on the screen.

2. Set up your track and cart to use the motion sensor. The sensor is made to clip into the track. Set the sensor to the “narrow beam” setting.

3. Your goal is to create simultaneous position-time and velocity-time graphs for a coasting collision cart. You only need to show a one-way trip. Adjust the equipment so that the plots are as smooth as possible. Make the cart move away from the motion sensor and catch it with your hand. Figure out how to adjust the axes of the graphs to obtain the best possible display of your plots.

4. When you obtain a show-quality graph, analyze the graphs to measure the speed of the coasting cart. Do this two ways: by measuring the average value of the points plotted in the velocity graph, and by measuring the slope of the points in the distance graph. Find the slope as described before. To measure the mean value of the points in the velocity graph, pull down the velocity graph’s Statistics Menu (\( \Sigma \) ) button, select Mean, and select some points from a smooth section of the graph.

5. Print a copy of these graphs for each group member, and write both velocity measurements on these graphs.

6. Repeat this procedure, but this time have the cart move toward the motion detector. Print a copy of the graph again, writing both velocity measurements on the graphs.

Part V: Comparing Distance and Velocity Graphs

1. Move the motion sensor so it will measure the motion of a person again. Flip the switch on the motion sensor to the “wide-beam” setting.

2. In the Part V section of the answer sheet, there are two pairs of distance-time and velocity-time graphs. For each, you will try to move in a way that matches the given graph.

3. Take data, and then sketch the corresponding velocity-time graph with a solid line. You may need to try each graph several times before you obtain a smooth graph.

4. The third graph in the Part V section of the answer sheet is a velocity-time graph. Try to move in a way that matches that \( v-t \) graph and then sketch the corresponding distance-time graph.
**Part I**

<table>
<thead>
<tr>
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<td>1</td>
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<td>10</td>
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</table>

**Part II**

**Away, Slow**

| Distance (m) | Time (s) |

**Away, Medium-Fast**

| Distance (m) | Time (s) |
Part III

Toward, Slow

Distance (m)

Time (s)

Go Stop Go

Distance (m)

Time (s)

Toward, Medium-Fast

Distance (m)

Time (s)

Away, Slow

Velocity (m/s)

Time (s)

Away, Medium-Fast

Velocity (m/s)

Time (s)
Part V

Toward, Slow

Toward, Medium-Fast

Go Stop Go

Actual Graph
<table>
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<th>Time (s)</th>
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<td></td>
<td>0 m/s</td>
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</thead>
<tbody>
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</tbody>
</table>
Questions

Write answers for the following questions. Attach a separate sheet, if necessary.

1. What did you do to try to make your velocity measurements as constant as possible in Part I? Were you successful? What would have been a better technique? What number did you measure that expresses how well you did at making the velocities the same?

2. Was there a difference in the velocity measurements that were made with the small pattern on the card in Part I, compared to those made with the large pattern on the card? Why or why not?

3. How did the computer calculate velocities in Part I? What did it have to know and what did it measure?

4. Describe the difference in x-t graphs made by walking away slowly and by walking away quickly.

5. Describe the difference in x-t graphs made by walking toward and by walking away from the motion detector.

6. How did you have to move to produce the two curved graphs in Part II? What type of motion is necessary to produce a curved distance-time graph?

7. In Part IV, you measured speed two different ways. Which do you think produces the more accurate measurement, averaging the values in the v-t graph, or measuring the slope of the x-t graph? Why?
Phys-111 Lab 2
Pre-Lab Preparation Sheet

1. When you make graphs of the motion of the fan cart, how many graphs will be displayed? Which ones?

2. How many different ways will you use your graphs to calculate accelerations?

3. Describe how you will use a position graph to calculate accelerations in Part I step #6.

4. How will the fan cart move while you take data in Part VII?

5. What happens at time D in Part VII?
Lab 2: Changing Motion

Objective: To study accelerated motion in the physics laboratory.

Procedure

Part I: Acceleration from Rest- Low Fan Setting Away from the Motion Sensor

1. Obtain a fan cart and motion sensor. Level your track. Connect the motion sensor’s stereo phone plugs to Digital Channels 1 and 2 on the interface. The yellow plug always goes in Channel 1.

2. Configure your software to display three graphs of the cart’s motion: position, velocity and acceleration vs. time. Drag a new digital plug onto Channel 1, and select Motion Sensor. Click <OK> at the next screen. Drag a new graph onto Channel 1, and select Position, x, (m), then hold down the <shift> key while you select Velocity, v (m/s) and Acceleration, a, (m/s^2) and click <OK>. Minimize the controller window. Resize and reposition the graph window so that it takes up the rest of the screen but does not cover the controller window. Display statistics for the graphs, by clicking on the statistics (Σ) button.

3. Turn the fan to the low setting of the switch and record the cart’s motion as it travels away from the sensor. Please catch the cart with your hand and Be Careful! Click on REC to take data and click STOP immediately after you stop the cart.

4. In order to be able to analyze these graphs, it is important that you obtain a smooth run. Make more runs with the fan cart if necessary.

5. Rescale these graphs and print one for each member of your group. At the top of your graph sheet, write the title “Low Setting Away.”

6. We will now measure the acceleration of the cart three ways: one for each graph. Display stats. For the position graph, select Curve Fit, Polynomial Fit. Highlight a smoothly curving section to be fit. Observe how well the fit line matches the data points. The polynomial that is fitted to your data will be second order, of the form y = a1 + a2 x + a3 x^2. Comparing this to the equation of motion of the cart, x = 1/2 at^2 + v_o t + x_o, we can see that the acceleration of the cart is equal to 2 times a3. Calculate a = 2 a3. Record this value on the position graph.

7. Measure the maximum and minimum position values that were measured during your run. Record these values on the position graph.

8. For the velocity graph, select Curve Fit, Linear Fit. Highlight the part to be fit, and make sure the fit line follows the points on the graph. The parameter “a2” is the slope of the graph, and is therefore equal to the acceleration of the cart. Record this value on the velocity graph.

9. Measure the maximum and minimum velocity values that were measured during your run. Record these values on the velocity graph.

10. For the acceleration graph, select Mean, and highlight a smooth flat section. The mean value of y is the acceleration of the cart. Record this value on the acceleration
graph. Find the average of the three acceleration values and record the average in the Summary Table. Click the statistics button to remove the statistics column. Then click on the rescale button.

**Part II: Acceleration from Rest- High Fan Setting Away from the Motion Sensor**

1. Repeat the procedure from *Part I* with the fan cart switched on “high,” and moving away the motion sensor. This time, title your graph sheet “High Setting Away.” Again, write all three acceleration values and the maximum and minimum values for position and velocity on the printed graphs. Find the average of the three acceleration values and record the average in the Summary Table.

**Part III: Acceleration from Rest- Low Fan Setting Toward the Motion Sensor**

1. Repeat the same procedure with the fan cart switched on “low,” and moving toward the motion sensor. This time, title your graph sheet “Low Setting Toward.” Again, write all three acceleration values and the maximum and minimum values for position and velocity on the printed graphs. Find the average of the three acceleration values and record the average in the Summary Table.

**Part IV: Acceleration from Rest- High Fan Setting Toward the Motion Sensor**

1. Repeat the same procedure with the fan cart switched on “high,” and moving toward the motion sensor. This time, title your graph sheet “High Setting Toward.” Again, write all three acceleration values and the maximum and minimum values for position and velocity on the printed graphs. Find the average of the three acceleration values and record the average in the Summary Table.

**Part V: Deceleration- Low Fan Setting Toward the Motion Sensor**

1. Repeat the same procedure again, but this time start with the cart at the far end of the kinematics track with the fan blowing away from the sensor. Use the low setting for the fan. Give the cart a brief push so that it travels toward the sensor, slows down, and stops. Stop taking data when the cart stops. After you print this graph and record the three accelerations and the maximum and minimum values for position and velocity, label the v-t graph with A at the time you started pushing, B at the time you stopped pushing, and C at the time where the cart turned around. Title this graph “Slowing Down Toward.” Find the average of the three acceleration values and record the average in the Summary Table.

**Part VI: Deceleration- Low Fan Setting Away from the Motion Sensor**

1. Repeat the procedure again, but this time start with the cart about 0.5 m away from the motion sensor with the fan blowing toward the sensor. Use the low setting for the fan. Give the cart a brief push so that it travels away from the sensor, slows down,
and stops. Stop taking data when the cart stops. After you take data, print this graph and record the accelerations and the maximum and minimum values for position and velocity, then label the $v$-$t$ graph with A at the time you started pushing, B at the time you stopped pushing, and C at the time where the cart turned around. Title this graph “Slowing Down Away.” Find the average of the three acceleration values and record the average in the Summary Table.

**Part VII: Round Trip- Low Fan Setting Away from the Motion Sensor**

1. Repeat the procedure again, but this time start with the cart about 0.5 m away from the motion sensor with the fan blowing toward the sensor. Use the low setting for the fan. Give the cart a brief push so that it travels away from the sensor, slows down, and moves back toward the sensor. Stop taking data when the cart returns to its original position. After you print this graph and record the accelerations and the maximum and minimum values for position and velocity, label the graphs with A at the time you started pushing, B at the time you stopped pushing, C at the time where the cart turned around, and D where you stopped the cart. Title this graph “Turning Around.” Find the average of the three acceleration values and record the average in the Summary Table.

2. On the velocity graph on your computer screen, find the velocity of the cart at each of these times. Record these values in the table on the answer sheet.
Name_____________________________

Phys-111 Lab 2
Answer Sheet

Summary Table

<table>
<thead>
<tr>
<th>Average Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part I</td>
</tr>
<tr>
<td>Part II</td>
</tr>
<tr>
<td>Part III</td>
</tr>
<tr>
<td>Part IV</td>
</tr>
<tr>
<td>Part V</td>
</tr>
<tr>
<td>Part VI</td>
</tr>
<tr>
<td>Part VII</td>
</tr>
</tbody>
</table>

Part VII

<table>
<thead>
<tr>
<th>Time</th>
<th>Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. When you measure an acceleration value that is toward the motion sensor, how is it mathematically different from an acceleration that is away from the sensor?
2. Compare the magnitude of the accelerations you measured for “High Setting Away” and “High Setting Toward.” Use the value you obtained from the v-t graphs. Calculate the percent difference in the two, comparing them to the “High Setting Away” run. Use the equation \( \% \text{dif} = \frac{\text{toward} - \text{away}}{\text{away}} \times 100 \). Then do the same thing, but compare “Low Setting Away” to “Low Setting Toward.” Are these two percentage differences related?
3. When measuring accelerations with three different graphs, which gives the most reliable results? Why do you think that?
4. In your “Turning Around” graph, what was the sign of the acceleration as the cart slowed down? What was the sign of the acceleration as the cart sped up? Explain why this might seem odd, and its physical significance.
5. Comparing the three graphs for each of your runs, which is the smoothest? The bumpiest? Why is that?
Phys-111 Lab 3
Pre-Lab Preparation Sheet

1. Why is it necessary to calibrate the force sensor?

2. What is the name of the software application you will use to make a graph of the force exerted by multiple rubber bands vs. the number of bands?

3. Describe how you will make the cart move in Part II.

4. Describe the method you will use to measure acceleration in Part II.

5. What sort of graph will be created in Part III?
Lab 3: Force and Motion

Objective: To develop a method for measuring forces, learn how to use a force probe, and study accelerated motion under an applied force to test Newton’s Second Law of Motion.

Procedure

Part I: Measuring Forces

1. Acquire five super-sized rubber bands, a meter stick, and a force probe.
2. Attach one end of the rubber band to something solid. Set the meter stick next to the rubber band. Pull the rubber band several centimeters beyond its relaxed position and note this stretched length as one Standard Length of the rubber band, to be used in the following steps of the procedure.
3. Plug the force probe into Analog Channel A in the interface box and run Science Workshop. Drag an analog plug to Analog Channel A and select Force Sensor. Create a digital display of the force by dragging the Digits icon to Analog Channel A.
4. Double-click on the Force Sensor’s icon to open the Force Sensor setup window. Make sure that nothing is pulling on the Force Sensor’s hook and press the Tare button. You may need to zero the sensor periodically during this procedure. Make sure the High Value in the Force Sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value 2 in the Low Value window and press <Read>. The Force Sensor is now calibrated.
5. Attach one end of a rubber band to something solid and the other end to the Force Sensor’s hook. Pull the rubber band horizontally so that it is stretched to one Standard Length. Acquire a steady reading and record this force in the table on your answer sheet.
6. Repeat this procedure for 2, 3, 4, and 5 rubber bands, recording each reading in the table.
7. Use Vernier Graphical Analysis to graph the amount of force against the number of rubber bands. First, run the Graphical Analysis program. It will be in the launcher on the desktop or you can run it from the Physics folder on the Concordia 3 server. After you have run the program, change the Label in the first data column from X to Rubber Bands, and the Y in the second column to Force. In the “Units” cell for the second column enter newtons. Enter your measurements in the appropriate cells. The points will be plotted automatically. Click on the graph window to make it active, then pull down the Analyze menu to Automatic Curve Fit. Click <OK>. Pull down the File menu to Print Graph, and print a copy for each person in your group, to be included with your answer sheet.
Part II: Force and Acceleration

1. In Part II, a cart will be accelerated by a constant force, and we will determine the mathematical relationship that exists between force and acceleration. To do this, we will measure several pairs of force and acceleration values and graph them against each other. Acquire a dynamics cart and use the small Phillips screwdriver to attach a force sensor to it. Get a motion sensor and plug it into Digital Channels 1 and 2 (yellow plug in #1). Plug the force sensor into Analog Channel A. Acquire a table clamp, string, pulley and mass set. Set up the equipment as shown in the following diagram.

2. Use a string that is 10 cm longer than the length needed to reach the floor when the cart is next to the pulley. Add 20 grams of mass to the mass hanger.

3. Open the Science Workshop configuration file called “Constant Force” in the Lab 3 folder inside Concordia Labs in the Phys-111 folder on your computer desktop.

4. Press the Tare button on the force sensor while nothing is pulling on it. Press REC and allow the mass to fall toward the floor, accelerating the cart. Press STOP after you catch the cart. Make sure the equipment is operating correctly so that you acquire a smooth set of graphs.

5. Click on the statistics (Σ) button. Click on the Autoscale button. On the force graph, click on the Statistics Menu (Σ▼) button. Select Mean from the menu. Drag a rectangle to select a smooth level portion of the force graph. The average reading from the force sensor will be displayed. Record this value in the appropriate table on the answer sheet.

6. To measure the acceleration of the cart, click on the Statistics Menu (Σ▼) button of the velocity graph and select Curve Fit, Linear Fit from the menu. Drag a rectangle to select a smooth portion of the velocity graph and fit a straight line to the data. The slope of the line (a2) is the acceleration in m/s². Record this value in the table.
7. Make more runs with the cart, with 40, 60, 80 and 100 grams on the mass hanger. For each run, record the force and acceleration values in the table.

8. Make a graph of acceleration vs. applied force for your four runs. Run Vernier Graphical Analysis to make the graph. This time replace the label for X with Force and Y with Acceleration. The units for Force should be newtons and the units for Acceleration should be m/s². Enter the Force and Acceleration values from your table in Part III into the columns in Graphical Analysis. Click on the graph window to make it active, then pull down the Analyze menu to Automatic Curve Fit. Click <OK>. Pull down the File menu to Print Graph, and print a copy for each person in your group, to be included with your answer sheet.

9. From the graph you just printed, obtain the regression equation, the equation of the line fitted to your data points. We will use this equation to predict accelerations for masses outside of the range of masses that have been measured so far.

10. Make the Science Workshop program active again. Hang 10 g of mass from the mass hanger and allow the string to pull on the force sensor while you hold the cart completely still. Press REC and allow measurements to be taken without letting go of the cart. After a flat line appears in the force graph, press STOP. Drag a rectangle to select a smooth level portion of the force graph. The average reading from the force sensor will be displayed. Record this value in the second table for Part III on the answer sheet.

11. Substitute this value for force in the regression equation and calculate the acceleration that it will cause. Write this predicted value in the table as the Predicted Acceleration.

12. Press REC and allow the mass to fall toward the floor, accelerating the cart. Press STOP after you catch the cart. Drag a rectangle to select a smooth portion of the velocity graph and fit a straight line to the data. The slope of the line (a2) is the acceleration in m/s². Record this value in the table as the Measured Acceleration.

13. Compare the predicted and measured values by calculating the percent difference between the two, using the formula
\[
\text{%dif} = \frac{\text{predicted} - \text{measured}}{\text{measured}} \times 100
\]

14. Repeat steps #10-13 using masses of 150 g and 200 g. Record all values in the data table on the answer sheet.

Part III: Pushing and Pulling

1. Open the Science Workshop configuration file called “Push-Pull” in the Lab 3 folder inside Concordia Labs in the Phys-111 folder on your computer desktop. A graph of Force vs. Acceleration will be displayed.

2. Set up the motion sensor and cart as shown in the following diagram and prepare to take data.
3. Grab the Force Sensor hook and press MON. Move the cart back and forth to make sure data is being taken properly, especially by the motion sensor. It should be on its narrow beam setting. Make sure you pull the force probe hook along a straight line parallel to the ramp. Do not twist the hook. Be sure that the cart never gets closer than 0.5 m away from the motion sensor. Then press REC to record data. When you hear the clicks, begin pulling and pushing the hook of the force sensor to make the cart move back and forth. Push and pull the cart back and forth four or five times. Then press STOP. Repeat if necessary to obtain a smooth graph. When you have obtained a smooth graph, click on the Rescale button.

4. Print one copy of your graph for each group member, to be attached to the answer sheet.
**Part I**

<table>
<thead>
<tr>
<th>Number of Rubber Bands</th>
<th>Force Sensor Reading (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

**Part II**

<table>
<thead>
<tr>
<th>Force Sensor Reading (N)</th>
<th>Acceleration (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

**Part III**

<table>
<thead>
<tr>
<th>Extra Mass on Hanger</th>
<th>Force Sensor Reading (N)</th>
<th>Predicted Acceleration (m/s²)</th>
<th>Measured Acceleration (m/s²)</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 g</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Item**

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of cart &amp; sensor (slope)</td>
<td></td>
</tr>
<tr>
<td>Mass of cart &amp; sensor (measured)</td>
<td></td>
</tr>
</tbody>
</table>
Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. How was the force exerted by multiple rubber bands mathematically related to the number of rubber bands used? Write the equation of the fitted line. Use this equation to predict the force that would be exerted by 12 rubber bands (in arbitrary units).
2. Write the regression equation for the line fitted to your graph in Part II. What is the slope of the graph (magnitude and units)?
3. Comment on the percent differences in the second table for Part II, accounting for possible sources of error.
4. What is the shape of the curve in the graph you obtained in Part III? Write a mathematical statement relating the quantities Force and Acceleration.
1. Describe how the cart will move while you take data in Part I.

2. Write the equation you will use to calculate the average acceleration in Parts I and II. How will you measure $v_i$, $t_i$, $v_f$, and $t_f$?

3. What quantities will you graph against each other in Part II?

4. Describe the method you will use to measure the forces exerted by the fans in Part III.

5. How will the apparatus be configured differently in Part IV compared to Part III?
Lab 4: Combining Forces

Objective: To further investigate how forces cause accelerations and explore the effect of combined forces in dynamical systems.

Procedure

Part I: Forces and Deceleration

1. In this part of today's lab, we will measure forces and accelerations for a decelerating kinematics cart. Acquire a force sensor, motion sensor, dynamics cart, a mass set, two 5-N spring scales, a table clamp, a pulley and some string. Attach the force sensor to the dynamics cart with the small screwdriver. Set up the apparatus as illustrated below. Level the kinematics track. Use enough string so that the mass hanger is about 10 cm from the floor when the cart is next to the pulley. Plug the Force Sensor into Analog Channel A, and the Motion Sensor into Digital Channels 1 and 2 (yellow plug in Channel 1).

![Diagram of apparatus](image)

2. Place 20 g of mass on the mass hanger. Open the Science Workshop file called “Deceleration” in the Lab 4 folder inside Concordia Labs in the Phys-111 folder. Double-click on the Force Sensor’s icon to open the Force Sensor setup window. Make sure that nothing is pulling on the Force Sensor’s hook and press the Tare button. You may need to zero the sensor periodically during this procedure. Make sure the High Value in the Force Sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value 2 in the Low Value window and press <Read>. The Force Sensor is now calibrated.

3. Start with the cart next to the pulley. Press MON and give the cart a push so that it travels toward the motion sensor and comes within about 50 cm of it, slows down, and stops. Catch the cart right when the cart stops and press STOP. Make sure the
motion sensor is on narrow beam setting. Practice if necessary so that data is being taken smoothly and you are pushing with the right amount of force. Then press REC and take data in a “live” run.

4. Click on the statistics (Σ) button. Click on the Autoscale button. On the force graph, click on the Statistics Menu (Σ ▼) button. Select Mean from the menu. Drag a rectangle to select a smooth level portion of the force graph. The average reading from the force sensor will be displayed. Record this value in the first line of the table on the answer sheet.

5. In previous labs, we have measured accelerations by fitting a straight line to data in the v-t graph. In this experiment, we will calculate the acceleration with the equation 

\[ a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} \]

where \( v_i \) and \( t_i \) are the initial velocity and time and \( v_f \) and \( t_f \) are the final velocity and time. We will take the initial point to be the moment when you released the cart after pushing it. Measure \( v_i \) and \( t_i \) by using the Crosshairs Tool. Click on this button \( \text{Crosshairs Tool} \). Now when you move the cursor over a graph, the exact coordinates of the center of the crosshairs will be displayed near the graph titles. Place the crosshairs over the point where you released the cart and record \( v_i \) and \( t_i \) in the table. Pay attention to negative values! Then measure \( v_f \) and \( t_f \) at the moment the cart was stopped. Calculate the acceleration with the equation above and record in the table.

6. Repeat this procedure, with 50, 100 and 150 grams on the mass hanger. For each run, record the values in the table.

7. Make a graph of acceleration vs. applied force for your four runs. Run Vernier Graphical Analysis to make the graph. Replace the label for X with Force and Y with Acceleration. The units for Force should be newtons and the units for Acceleration should be \( \text{m/s}^2 \). Enter the Force and Acceleration values from your table in Part III into the columns in Graphical Analysis. Click on the graph window to make it active, then pull down the Analyze menu to Automatic Curve Fit. Click <OK>. Pull down the File menu to Print Graph, and print a copy for each person in your group, to be included with your answer sheet. At the top of this graph, write “Deceleration.”

Part II: Force and Acceleration During a Round Trip

1. In this part of the lab, we will measure forces and accelerations for a kinematics cart that decelerates, stops, and accelerates back to its original starting point. Hang 20 g of mass on the mass hanger. Start with the cart next to the pulley. Press MON and give the cart a push so that it travels toward the motion sensor and comes within about 50 cm of it, slows down, and returns to the original starting point. Press STOP after you catch the cart. Make sure the motion sensor is on narrow beam setting. Practice if necessary so that data is being taken smoothly and you are pushing with the right amount of force. Then press REC and take data in a “live” run.

2. Click on the statistics (Σ) button. Click on the Autoscale button. On the force graph, click on the Statistics Menu (Σ ▼) button. Select Mean from the menu. Drag a
rectangle to select a smooth level portion of the force graph. The average reading from the force sensor will be displayed. Record this value in the first line of the table on the answer sheet.

3. Calculate the acceleration as before, measuring \( v_i, t_i, v_f \) and \( t_f \) with the Crosshairs Tool. Take the initial point to be the moment you released the cart, and the final point to be the moment just before you caught the cart. Pay attention to negative values! Record all values in the table.

4. Repeat this procedure, with 50, 100 and 150 grams on the mass hanger. For each run, record the force and acceleration values in the table.

5. Make a graph of acceleration vs. applied force for your four runs. Run Vernier Graphical Analysis to make the graph. Replace the label for \( X \) with Force and \( Y \) with Acceleration. The units for Force should be newtons and the units for Acceleration should be \( m/s^2 \). Enter the Force and Acceleration values from your table in Part III into the columns in Graphical Analysis. Click on the graph window to make it active, then pull down the Analyze menu to Automatic Curve Fit. Click <OK>. Pull down the File menu to Print Graph, and print a copy for each person in your group, to be included with your answer sheet. At the top of this graph, write “Round Trip.”

Part III: Adding Forces

1. Acquire two fan carts. Put a piece of tape on one of the carts to designate it as Fan Cart 1. We will now measure the force that is exerted when the fan is blowing. First, enlarge the controller window and drag a new digits display to the Force Sensor icon. Connect a fan cart to the Force Sensor with a small piece of string. Place the fan cart on the kinematics track and make sure the force sensor can’t move. Turn the fan cart switch on HIGH so that the fan is pushing the cart away from the force sensor. Measure the force from the fan and record in the table on the answer sheet. Repeat for the second fan cart.

2. Measure the force of both fans on HIGH acting together. To do this, tie the carts together with a short piece of string so the carts are bumper to bumper. Make sure the fans are turned so they both push the carts away from the force sensor. Record the combined force in the table.

3. Next, we will measure the accelerations of the fan carts as the fans move along the track, powered by Fan 1, Fan 2, and both fans acting together. The fan carts should still be connected with a string. Open the Science Workshop configuration called “Fan Carts” in today’s lab folder. Don’t save the old experiment. Set up the carts so that they are 50 cm from the Motion Sensor with the fans set to push the carts away from the Motion Sensor. Use the MON button to make sure the sensor is operating correctly. Then use REC to take data while the two carts move away from the sensor with only Fan 1 blowing on HIGH. Fit a line to a smooth section of the velocity-time graph to measure the slope of the line, and record this acceleration in the data table. To do this, click on the statistics button (\( \Sigma \)), then pull down the statistics menu for the \( v-t \) graph and select Curve Fit \( \rightarrow \) Linear Fit. Highlight a smooth section of the graph and make sure the fitted line follows the data. The slope is given as the number for “a2.”
4. Repeat with only Fan 2 blowing on HIGH, then for both fans blowing together on HIGH. Record the accelerations in the table.

5. Repeat steps 1-3, this time with only Fan 1 blowing on LOW, then with only Fan 2 blowing on LOW, then for both fans blowing together on LOW. Record the forces and accelerations in the table.

**Part IV: Subtracting Forces**

1. Change the configuration of the fan carts so that they are connected by a short string, bumper-to-bumper, and their fans blow in opposite directions.

2. Place the carts at the center of the ramp and turn both fans on LOW. With both fans blowing, record a run for the carts moving away from the motion sensor. Start them 50 cm from the sensor and give them a brief push with your hand. Fit a line to the $v$-$t$ graph to measure the acceleration of the carts and record this value in the table on the answer sheet.
**Phys-III Lab 4**  
*Answer Sheet*

**Part I**

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>$v_f$ (m/s)</th>
<th>$v_i$ (m/s)</th>
<th>$t_f$ (s)</th>
<th>$t_i$ (s)</th>
<th>$a$ (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

**Part II**

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>$v_f$ (m/s)</th>
<th>$v_i$ (m/s)</th>
<th>$t_f$ (s)</th>
<th>$t_i$ (s)</th>
<th>$a$ (m/s$^2$)</th>
</tr>
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</table>

**Part III**

<table>
<thead>
<tr>
<th></th>
<th>Average Force (N)</th>
<th>Average acceleration (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fan Cart 1: <strong>HIGH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan Cart 2: <strong>HIGH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Carts: <strong>HIGH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan Cart 1: <strong>LOW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan Cart 2: <strong>LOW</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Carts: <strong>LOW</strong></td>
<td></td>
<td></td>
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</tbody>
</table>

**Part IV**

<table>
<thead>
<tr>
<th></th>
<th>Average acceleration (m/s$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fans Blowing Against</td>
<td></td>
</tr>
<tr>
<td>Each Other</td>
<td></td>
</tr>
</tbody>
</table>
Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. In Parts I and II, you calculated the acceleration of the cart with the equation
   \[ a = \frac{v_f - v_i}{t_f - t_i}. \]
   How is this method mathematically similar to measuring the slope of a fitted line? Which technique do you think is more reliable? Why?
2. Look at the graph titled “Deceleration.” What is the mathematical relationship between force and acceleration for a decelerating cart?
3. Look at the graph titled “Round Trip.” What is the mathematical relationship between force and acceleration for a cart that slows down, stops and turns around under the influence of a constant force?
4. In Part III, how are the accelerations for the carts with a single fan blowing mathematically related to the acceleration with both fans blowing?
5. In Part IV, what acceleration did you measure? What does this imply about the net force acting on the carts?
1. For each value of the mass in Part I, how many trials will be measure?

2. Given that the mass of the cart will be increased in equal increments in the five runs in Part I, what is the approximate mass of a weight bar?

3. In Part II, you will create two graphs with Vernier Graphical Analysis. Both graphs will plot acceleration on the vertical axis. What will be plotted on the horizontal axes for the two graphs?

4. What is the goal of Part III?

5. What technique will be used to measure the acceleration in Part III?
Lab 5: Force, Mass, and Acceleration

Objective: To investigate the mathematical relationships between force, mass and acceleration.

Procedure

Part I: Varying Mass with Constant Force

1. Obtain a dynamics cart, smart pulley, table clamp, a spring scale, some string, two bar masses and a mass set. Set up your kinematics track as shown below. Level the track as carefully as possible.

2. Plug the smart pulley into Digital Channel 1. Open the Science Workshop configuration file called “Smart Pulley” in today’s lab folder.

3. Attach a string to the cart and a mass hanger to the string. Use a string that is long enough so that when the cart is next to the smart pulley and the string is over the pulley, the string almost touches the floor. Place 50 g on the mass hanger. The total hanging mass for all the runs in this procedure will be 55 g, including the mass hanger.

4. Pull the cart back so that the hanging mass is as high off the floor as possible. Release the cart from a stationary position and let it travel as far as it is able, while still accelerating. Don’t let the cart hit the pulley! Click on the MON button and make a few runs to verify that the acceleration is being calculated properly. Note that it is best to start a “run” with the photogate beam of the smart pulley off.

5. Use REC and STOP to obtain a “good” trial and use your onscreen graph to calculate its acceleration. To do this, click on the statistics button (Σ), then pull down the statistics menu for the v-t graph and select Curve Fit → Linear Fit. Highlight a smooth section of the graph and make sure the fitted line follows the data. The slope
is given as the number for “a2.” Record this acceleration in the **Trial Data** table on the answer sheet.

6. Repeat this procedure four more times so that you have five acceleration measurements in the **Trial Data** table. Add these five accelerations and divide by five to obtain the average acceleration for 1.0 cart mass. Record this in the table.

7. Take your dynamics cart to the front of the room and weigh it on the electronic balance. Place it on the balance upside-down so it doesn’t roll off while you weigh it. To this value, add 55 g for the hanging mass, convert to kilograms and record in the table as the mass for Run #1.

8. Place 250 g from the mass set onto the top of the cart. Add 0.250 kg to the mass for Run #1 and record this mass as the mass for Run #2. Repeat the procedure described above to obtain five acceleration measurements for Run 2 and record them in the **Trial Data** table. Calculate the average for these five trials and record in the table.

9. For Run #3, place a weight bar on top of the cart. Measure its mass on the electronic balance, add this amount in kilograms to the mass for Run #1 and record in the table as the mass for Run #3. Repeat the procedure described above to obtain five acceleration measurements for Run 3 and record them in the **Trial Data** table. Calculate the average for these five trials and record in the table.

10. For Run #4, leave the weight bar on top of the cart and add another 250 g from the mass set. Add 0.250 kg to the mass for Run #3 and record this mass as the mass for Run #4. Repeat the procedure described above to obtain five acceleration measurements for Run #4 and record them in the **Trial Data** table. Calculate the average for these five trials and record in the table.

11. For Run #5, place both weight bars on top of the cart. Measure the mass of the second weight bar on the electronic balance, add this amount in kilograms to the mass for Run #3 and record in the table as the mass for Run #5. Repeat the procedure described above to obtain five acceleration measurements for Run #5 and record them in the **Trial Data** table. Calculate the average for these five trials and record in the table.

12. The mass of your hanging mass has been 55 g. Use a 5-N spring scale to measure the **weight** of this mass, in newtons. Record this measurement as the **Actual applied force** on the answer sheet.

**Part II: Analyzing the Data**

1. Write the five average acceleration values from the **Trial Data** table in the appropriate rows of the **Avg. Acceleration** column of the **Summary Table**.

2. Copy the **Mass** values from the **Trial Data** table into the last column of the **Summary Table** for each of the five runs.

3. Run **Vernier Graphical Analysis**. In the data table, change the X label to **Mass** with units of **kg**, and change the Y label to **Acceleration** with units of **m/s^2**. Enter the **Mass** values from your **Summary Table** into the **Mass** column. Enter the average acceleration values from the **Summary Table** into the **Acceleration** column. The points will be automatically plotted on the graph. Pull down the **Analyze** menu and select **Automatic Curve Fit**… Click the **Inverse** button. Click <OK>. Pull down the
File menu to Print Graph...and print a copy of this graph for everyone in your group. At the top of this graph, write the title “Acceleration vs. Mass.”

4. Pull down the Data menu in Vernier Graphical Analysis and select New Column. Change the label of this column from X to =1/Mass. This entry is case-sensitive and must be entered exactly like you entered the label in the first column. On the graph that is displayed, click on the label on the horizontal axis. A menu will appear. Select =1/Mass. A new graph will now be plotted. Now pull down the Analyze menu and select Automatic Curve Fit... Click the Linear button. Click <OK>. Pull down the File menu to Print Graph...and print a copy of this graph for everyone in your group. At the top of this graph, write the title “Acceleration vs. 1/Mass.”

Part III: The Proportionality Constant

1. In order to verify that \( F = ma \) when units are suitably chosen, we will now accelerate a mass of one kilogram with a force of one newton to see if an acceleration of one meter per second squared results. Acquire a force sensor and attach it to the collision cart with a small screwdriver. Set up your equipment as shown below.

2. Tape masses to the cart along with the force probe so that the total mass of the cart is 1.0 kg. Record the mass of the cart in the table for Part III.

3. Open the Science Workshop file called “Smart Pulley with Force Sensor.”

4. Calibrate the force sensor. To do this, double-click on the Force Sensor’s icon to open the Force Sensor setup window. Make sure that nothing is pulling on the Force Sensor’s hook and press the Tare button. Make sure the High Value in the Force Sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value 2 in the Low Value window and press <Read>. 
5. Start with a hanging mass of about 100 g. Press REC and allow the cart to be accelerated. Highlight a smooth level section of the force graph and note the mean value. Try different hanging masses until you get an applied force of close to 1.0 N while the cart is accelerating.

6. When the applied force is as close to 1.0 N as you can make it, record a run. Drag a rectangle to select a smooth portion of the velocity graph and fit a straight line to the data. The slope of the line (a2) is the acceleration in m/s$^2$. Record this value in the table for Part III. Drag a rectangle to select a smooth level portion of the force graph. The average reading from the force sensor will be displayed. Record this value in the table.
**Phys-111 Lab 5**  
*Answer Sheet*

**Part I**

Trial Data

<table>
<thead>
<tr>
<th>Run</th>
<th>Trial</th>
<th>Trial</th>
<th>Trial</th>
<th>Trial</th>
<th>Trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>#2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>#3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>#4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>#5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
<td>Avg</td>
</tr>
<tr>
<td>Mass</td>
<td>Mass</td>
<td>Mass</td>
<td>Mass</td>
<td>Mass</td>
<td>Mass</td>
</tr>
</tbody>
</table>

**Part II**

Actual applied force (N): ________________

Summary Table

<table>
<thead>
<tr>
<th>Run #</th>
<th>Mass (kg)</th>
<th>Avg. Acceleration (m/s^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part III**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of cart (kg)</td>
<td></td>
</tr>
<tr>
<td>Average acceleration (m/s^2)</td>
<td></td>
</tr>
<tr>
<td>Average applied force (N)</td>
<td></td>
</tr>
</tbody>
</table>
Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. What is the advantage of measuring five trials for each cart mass and averaging them, rather than using a single trial?
2. Examine your “Acceleration vs. Mass” graph. What is the equation of the fitted curve? Use this equation to predict the acceleration of a cart that weighs 4.2 kg.
3. Examine your “Acceleration vs. 1/Mass” graph. What is the equation of the fitted line? Use this equation to predict the acceleration of a cart that weighs 4.2 kg.
4. The slope of the fitted line for your “Acceleration vs. 1/Mass” graph should be equal to the actual applied force in your experiment. Calculate the percent difference between the actual applied force (measured) and the experimentally determined force for any discrepancy.
5. In Part III, is $F$ really equal to $ma$? Discuss possible sources of error.
1. What method will you use to measure \( g \) in \textit{Part II}?

2. What falling object will you study in \textit{Part IV}?

3. How many vectors will there be in your diagram for \textit{Part V}?

4. What will be plotted on the horizontal and vertical of the graph you make in \textit{Part VI}?

5. How many different ways will \( g \) be measured in this week’s lab exercise?
Lab 6: Gravitational Forces

Objective: To investigate the nature of the gravitational force and measure the acceleration of gravity using several different methods. To observe accelerated motion on an inclined kinematics track and investigate the normal force.

Procedure

Part I: Freely Falling Picket Fence

1. In this activity, a “picket fence” drops through a photogate. The computer will measure the times that the beam is blocked, and knowing the distance between the leading edges of each opaque band, will calculate the average speed of the picket fence as it falls. The slope of the graph of the average speed will be equal to the acceleration of gravity.

2. Obtain a picket fence and “cushion” bucket. Take a photogate from your Airtrack Supplies drawer and plug it into Digital Channel 1. Open the Science Workshop configuration file in today’s lab folder called “Picket Fence.”

3. Click on REC and drop the picket fence so it falls through the photogate into the bucket. Click on STOP. Click on the statistics button (Σ), then pull down the statistics menu for the v-t graph and select Curve Fit → Linear Fit. Click on the Autoscale button. Highlight a smooth section of the graph and make sure the fitted line follows the data. The slope is given as the number for “a2.” Record this average acceleration in the blank on the answer sheet as \( g \).

4. Calculate the percent error for the value of \( g \) you measured in Part I, using an accepted value of 9.80 m/s\(^2\). Use the formula \( \% \text{error} = \frac{g_{\text{measured}} - 9.80}{9.80} \times 100 \). Record this value on the answer sheet.

5. Measure the mass of the picket fence and record this value on the answer sheet. The net force that makes the picket fence fall is the weight of the picket fence. Tape a small loop of string to the picket fence and measure its weight on the spring scale. Record this value as \( F_{\text{net}} \) on the answer sheet. Use this force, along with the mass of the picket fence to calculate the expected acceleration of the picket fence, \( a = \frac{F_{\text{net}}}{m} \) and record.

Part II: Motion of a Falling Ball

1. Acquire a ball and a motion sensor. Unplug the photogate and connect the motion sensor to the interface box. Open the Science Workshop configuration file in today’s lab folder called “Motion Sensor.” Set the motion sensor on the “wide beam” setting. Have someone stand up and hold the motion sensor high above the floor pointing straight downward. Hold the ball at a position 50 cm below the motion sensor, press REC, and release the ball. Press STOP when the ball hits the floor. You may need
to experiment a few times to get a clean graph. You will need to make sure your hand is not in the path of the motion detector when you release the ball.

2. When you obtain a smooth graph, measure the average acceleration of the ball as before. Record this value for \( g \) on the answer sheet.

3. Calculate the percent error for the value of \( g \) you measured in Part II, using an accepted value of \( 9.80 \text{ m/s}^2 \). Record this value on the answer sheet.

Part III: Rising and Falling Ball

1. Repeat the procedure from Part II, but this time measure the motion of the ball as you throw it upward toward the motion sensor and allow it to fall back down to the floor. It may be tricky to throw it straight up so the motion sensor can detect the whole motion of the ball.

2. Measure the average acceleration as before, and record this value on the answer sheet. Calculate the percent error for the value of \( g \) you measured in Part III, using an accepted value of \( 9.80 \text{ m/s}^2 \). Record this value on the answer sheet and print a copy of the graph for each group member. Write the title “Rising and Falling Ball” at the top of the graph.

Part IV: Falling with Air Resistance

1. Obtain three coffee filters. Measure their mass, in kilograms, and record on the answer sheet.

2. Place the motion sensor flat on the floor pointing upward. Stack the three filters together and measure their motion as they fall onto the motion sensor. Drop the filters from high above the sensor, about 2 m if possible.

3. After you obtain a smooth graph, fit a straight line to the \( v-t \) graph during a brief time period immediately after the filters began to fall. Record this acceleration as \( a_1 \) on your answer sheet. Then fit a line to the \( v-t \) graph after the filters had fallen some distance and the curve had flattened out. Record this acceleration as \( a_2 \) on your answer sheet.

4. Since the coffee filters are so light and wide, we must consider the air resistance force in analyzing their motion. The weight of the coffee filters is equal to \( mg \) and pulls them downward, while the air resistance force, \( F_{\text{air}} \), pushes upward. So the net force pulling them downward is equal to \( F_{\text{net}} = mg - F_{\text{air}} \). And Newton’s Second Law tells us that \( F_{\text{net}} = ma \). Calculate the value of this net force for the time when the filter just began to fall using \( F_{\text{net} \, 1} = ma_1 \) and record on your answer sheet. Then find the net force acting on the filters during the second time interval using \( F_{\text{net} \, 2} = ma_2 \) and record.

5. Draw two vector diagrams for the filters on your answer sheet, showing the relative magnitude of the weight of the filters, \( mg \), and the air resistance force, \( F_{\text{air}} \). The first diagram should be during the time period when the net force was \( F_{\text{net} \, 1} \), and the second should be after the filters stopped accelerating, when the net force was \( F_{\text{net} \, 2} \). Make sure that the diagrams show the relative size of the two forces for the two time periods.
Part V: The Normal Force

1. Acquire a collision cart, two bar masses and a meter stick. Record the mass of the cart, in kilograms, in the space provided in Part V on your answer sheet.
2. Use two books to raise the kinematics track on the end with the bumper. This will incline the track at some angle, \( \theta \). Measure \( h \), the book height, and the length of the track, \( l \). As can be seen in the diagram below, \( \sin \theta \) is equal to \( h \), the book height, divided by the length of the track, \( l \). Use the relation \( \sin \theta = \frac{h}{l} \) to calculate the angle \( \theta \) and record this value on your answer sheet.

\[
\begin{align*}
& l \\
& \theta \\
& h
\end{align*}
\]

3. Tie a string to the cart and to the bumper so that the cart is held motionless on the inclined track.
4. The cart is now experiencing three balanced forces that hold it motionless, its weight, the tension force from the string, and a force exerted on it by the surface of the kinematics track, the normal force. The weight of the cart is equal to \( mg \). The string tension is equal to \( mg \sin \theta \). The normal force is equal to \( mg \cos \theta \). Draw a vector diagram on your answer sheet, labeling these three forces, including their magnitudes in newtons.

Part VI: Varying the Angle of an Inclined Track

1. A mass on an inclined plane experiences an acceleration along the plane equal to \( g \sin \theta \). In this part of today’s experiment, we will vary the angle of an inclined kinematics track and collect data that will allow us to make a graph of the acceleration vs. \( \sin \theta \). The slope of this graph should be equal to \( g \), the acceleration of gravity.
2. Clip the motion sensor into the kinematics track and use one textbook-sized book to raise the end of the ramp with the motion sensor. Start the cart about 30 cm from the motion sensor. Click REC and release the cart. Catch it with your hand at the bottom of the ramp while someone clicks on STOP.
3. Measure the average acceleration of the cart as before by finding the slope of the \( v-t \) graph, and record this acceleration in the Part VI table on the answer sheet.
4. Use a meter stick to measure the height of the end of the kinematics track in centimeters, and record this value in the table. Then measure the length of the kinematics track. Record this value in the blank provided on the answer sheet.
5. Using the relation \( \sin \theta = \frac{h}{l} \), calculate \( \sin \theta \) and record this value in the table.
6. Increase the steepness of the inclined track by adding a second book. Repeat the procedure and complete the second line of the table on the answer sheet.
7. Repeat the procedure twice more, using three and four books.
8. Run Vernier Graphical Analysis. In the data table, change the X label to Sin T with no units, and change the Y label to Acceleration with units of m/s^2. Enter the sin θ values from the Part V table into the Sin T column. Enter the average acceleration values from the table into the Acceleration column. The points will be automatically plotted on the graph. Pull down the Analyze menu and select Automatic Curve Fit… Click the Linear button. Click <OK>. Pull down the File menu to Print Graph…and print a copy of this graph for everyone in your group. At the top of this graph, write the title “Acceleration vs. sin θ.”

9. The slope of the fitted line is g, the acceleration of gravity. Record this value on the answer sheet. Calculate the percent error for this value, using an accepted value of 9.80 m/s^2. Record the percent error on the answer sheet.

Part VII: Varying the Mass of the Cart on an Inclined Track

1. Use the balance to measure the mass of your collision cart. Record this value as the mass of the Cart Only trial in the table for Part VII.

2. Use the same two books you used in the 2 Books trial in Part VI to elevate your kinematics track. In Part VI of the experiment, you ran a trial with this height. Record that result as the first Average Acceleration for Part VII.

3. Measure the mass of one weight bar. Add this mass to the mass of the cart and record this as the mass for the One Mass Bar trial, in kilograms. Allow the cart to accelerate down the track while you record data. Curve-fit the v-t graph and record the Average Acceleration value in the table.

4. Repeat the procedure with two bar masses on the cart.
Phys-111 Lab 6
Answer Sheet

Part I

\[ g = \underline{\quad} \text{m/s}^2 \quad \text{Percent Error:} \quad \underline{\quad} \]

\[ m = \underline{\quad} \text{kg} \quad F_{\text{net}} = \underline{\quad} \text{N} \quad a = \underline{\quad} \text{m/s}^2 \]

Part II

\[ g = \underline{\quad} \text{m/s}^2 \quad \text{Percent Error:} \quad \underline{\quad} \]

Part III

\[ g = \underline{\quad} \text{m/s}^2 \quad \text{Percent Error:} \quad \underline{\quad} \]

Part IV

\[ m = \underline{\quad} \text{kg} \quad a_1 = \underline{\quad} \text{m/s}^2 \quad a_2 = \underline{\quad} \text{m/s}^2 \]

\[ F_{\text{net}1} = \underline{\quad} \text{N} \quad F_{\text{net}2} = \underline{\quad} \text{N} \]

Vector Diagrams

Part V

\[ \text{Mass of Cart} = \underline{\quad} \text{kg} \quad \theta \text{ (degrees):} \quad \underline{\quad} \]

Vector Diagram
Part VI

<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Acceleration (m/s²)</th>
<th>Book Height (cm)</th>
<th>sin θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Book</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Books</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Books</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Books</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Track Length = __________ cm

g = __________ m/s² Percent Error: __________

Part VII

<table>
<thead>
<tr>
<th>Trial</th>
<th>Average Acceleration (m/s²)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cart Only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One Mass Bar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two Mass Bars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. When $g$ is measured by dropping a picket fence through a photogate, should the results depend on how high above the photogate the picket fence is dropped? Why or why not?
2. In Part I, you calculated an expected acceleration of the picket fence from the measured mass and weight, using $a = \frac{F_{net}}{m}$. How did this calculated value compare to the measured value?
3. Examine your “Rising and Falling Ball” graph from Part III. In Part III, what was the acceleration of the ball as it moved upward? Is this different from the acceleration as it moved downward? Why or why not?
4. Your analysis of the motion of the coffee filters in Part IV included air resistance. Is there any evidence that air resistance was an important factor in Parts I – III, or were we justified in ignoring it?
5. In Part VII, how did the accelerations for the different cart masses compare to each other? What does this imply about the acceleration of different-sized falling objects, when air resistance can be neglected?
6. In today’s lab, you measured the value of $g$ using four different methods. Compare the percent errors you calculated using these methods, and comment on possible reasons for differences in accuracy.
1. How fast will the block move when the hanging weight pulls on it in Part I?

2. What two values will you measure in order to calculate the static friction coefficient in Part II?

3. Why is it necessary to measure the acceleration of the block, in order to find the magnitude of the friction force in Part III?

4. How many trials will be conducted for each block surface in Part VI?

5. What’s different about the two “Tug-Of-Wars” that will be conducted in Part V?
Lab 7: Passive Forces and Newton’s Laws

Objective: To investigate the nature of frictional forces and verify Newton’s Third Law.

Procedure

Part I: Static Friction Force

1. Obtain a force sensor, a friction block, a Smart Pulley and table clamp, one mass bar, a mass set, a spring scale and some string. Measure the combined mass of the force sensor and the friction block and record this mass in kilograms on your answer sheet.

2. Plug the force sensor into Analog Channel A, and the Smart Pulley into Digital Channel 1. Open the Science Workshop file called “Smart Pulley with Force Sensor” in the Lab 7 folder inside Concordia Labs in the Phys-111 folder. Double-click on the force sensor’s icon to open the force sensor setup window. Make sure that nothing is pulling on the force sensor’s hook and press the Tare button. You may need to zero the sensor periodically during this procedure. Make sure the High Value in the force sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value 2 in the Low Value window and press <Read>. The force sensor is now calibrated.

3. Turn the force sensor upside-down and place it on top of the friction block so that the block rests inside the mass tray. Make sure that the felt side of the friction block is against the force sensor and the wood side is down. Set up the apparatus so that the string runs over the pulley and attaches to the hook on the force sensor. Hang a mass hanger from the other end of the string. Use enough string so that the mass hanger is about 10 cm from the floor when the block is next to the pulley. Adjust the height of the pulley so it pulls sideways against the force sensor hook. The friction block should move along a uniform section of the lab table as it is pulled by the string.

4. Place 100 grams of mass on the mass hanger. Allow the mass to pull against the force sensor hook. The block will not move because it is being held motionless by a static friction force that balances the sideways force exerted by the hanging mass.

5. While the string pulls against the force sensor’s hook, press REC. Data will be taken for three seconds. Highlight a smooth section of the force graph and write the mean force value as the Applied Force in the Part I table on your answer sheet.

6. Complete the table. The Static Friction Force is equal to the Applied Force, since the block and force sensor are not accelerating. Calculate the Weight of Block and Sensor using $W = mg$. Remember to convert the hanging mass to kilograms. The Normal Force is equal to the Weight of Block and Sensor.

7. Draw a free-body diagram on your answer sheet, labeling the four forces acting on the system.
Part II: Measuring the Static Friction Coefficient

1. Acquire a meter stick. Remove the friction block from beneath the force sensor and place it on your kinematics track, wood side down. Slowly lift one end of the track until the block just begins to slide. Use the meter stick to measure the height (in meters) to which the track is raised and record in the table for Part II. Then measure and record the length of the track.

2. At the inclination angle when the block just begins to slide, the force along the track is equal to the maximum static friction force, $f_{s\,(\text{max})}$. The first diagram below shows the four forces acting on the block at this moment. These four forces are: the component of the block’s weight causing it to move down the track, $mg \sin \theta$; the maximum static friction force, the component of the block’s weight pushing it into the track, $mg \cos \theta$; and the normal force, $N$. Since the static friction force is equal to $f_{s\,(\text{max})} = \mu_s N$, and is balanced with the force along the track $mg \sin \theta$; we can write $mg \sin \theta = \mu_s N$.

But the normal force is balanced with the component of the block’s weight pushing it into the track, $mg \cos \theta$; so $mg \sin \theta = \mu_s mg \cos \theta$.

Solving for the coefficient of friction, we get

$$\mu_s = \frac{mg \sin \theta}{mg \cos \theta} = \tan \theta.$$

3. Complete the data table on your answer sheet. From the second diagram above, we see that $\sin \theta = \frac{h}{l}$. Use this relation to find the angle of inclination of the track. Then use $\mu_s = \tan \theta$ to calculate the friction coefficient and record in the table.

4. Repeat the procedure, having each member of your group lift the track, to obtain three trials.

5. Calculate the average value you measured for $\mu_s$ and record this value in the last row of the table.

Part III: Kinetic Friction Force

1. Re-assemble the pulley system you used in Part I. Once the block and sensor are in motion, the applied force is resisted by the kinetic friction force. Make sure the block and sensor are positioned away from the pulley so the hanging mass is near the
pulley. Hold the system motionless while you add 200 g to the mass hanger. Press REC and allow the block and force sensor to be accelerated toward the pulley. Catch them before they hit the pulley.

2. Draw a free-body diagram in the space provided on your answer sheet that shows the four forces acting on the system when it is accelerating: the Applied Force, the Kinetic Friction Force, the Weight of the sensor and block, and the Normal Force. Make sure that the Applied Force is larger than the Kinetic Friction Force, so that the system was accelerating.

3. Complete the Part III table. Highlight a smooth section of the force graph that corresponds to the time when the system was accelerating and write this mean value in the table as the Applied Force. The Weight of Block and Sensor and the Normal Force are the same as they were in Part I. We have not directly measured the Kinetic Friction Force. This value must be calculated.

4. To find this force value, we note from the free-body diagram that the net force acting on the object is equal to the difference between the applied force and the friction force, i.e.

\[ F_{net} = F_a - f_k. \]

But Newton’s Second Law tells us that

\[ F_{net} = ma. \]

Substituting, we get

\[ ma = F_a - f_k, \]

which can be rearranged to yield

\[ f_k = F_a - ma. \]

To use this equation, we must measure the acceleration of the block and sensor. Highlight a smooth section of the \( v-t \) graph so that a curve is fit to the data. Make sure you highlight a section during a time when the system was accelerating. The slope of the fitted line, \( a_2 \), is the acceleration. Record this value in the space provided on the answer sheet. Then use the above equation to calculate the value of the Kinetic Friction Force and record in the table.

Part IV: Investigating Kinetic Friction

1. If we want to find the value of the kinetic friction coefficient, we can carry our mathematical analysis further. The kinetic friction force depends only on the kinetic friction coefficient and the normal force, \( f_k = \mu_k N \). So

\[ \mu_k N = F_a - ma. \]

But the normal force in our system is just equal to the weight of the sensor and block, \( mg \). Then we have

\[ \mu_k mg = F_a - ma. \]

Solving for the coefficient, our equation becomes

\[ \mu_k = \frac{F_a - ma}{mg}. \]
2. We will now vary the parameters of our system in order to see how the kinetic friction force is affected by the speed of the moving block, the magnitude of the normal force, and the nature of the sliding block’s surface.

3. For Trial 1, we will use the run just completed. Copy the values for \( F_a, N \) and \( a \) into the appropriate line on the table for Part IV. Then use the equation above to calculate the kinetic friction coefficient and record in the table.

4. For Trial 2, add another 50 grams to the hanging mass. Take data while the system accelerates and complete all values in the Trial 2 line of the table.

5. For Trial 3, do not change the amount of hanging mass. But add 200 g of mass to the top of the force sensor, securing it with tape. Repeat the procedure and complete the table.

6. For Trials 4-6, duplicate the conditions of Trials 1-4, but turn the friction block upside-down so that the felt side is against the table. Record all measured and calculated values in the table.

**Part V: Testing Newton’s Third Law**

1. Acquire a second force sensor and plug it into Analog Channel B. Open the *Science Workshop* file called “Two Force Sensors” in the *Lab 7* folder inside *Concordia Labs* in the *Phys-111* folder.

2. Double-click on the Channel A force sensor’s icon to open the force sensor setup window. Make sure that nothing is pulling on the force sensor’s hook and press the *Tare* button. You may need to zero the sensor periodically during this procedure. Make sure the High Value in the force sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value -2 in the Low Value window and press <Read>. Repeat for the second force sensor, but this time enter a value of +2 in the Low Value window. Both force sensors are now calibrated, and one sensor will read a pull as a positive force while the other will read a pull as a negative force. Minimize the controller window.

3. Hook a short loop of string between the hooks on the force sensors and allow them to rest on the table. Press REC and have two members of your group begin a gentle tug-of-war between the force sensors while they rest motionless on the table. Data will be taken for five seconds. Rescale the graphs and examine them for “bad” data points. Repeat if necessary and print a graph for each group member. At the top of this graph write the title “Motionless Tug-Of-War.”

4. Take data again, but this time allow one of the sensors to be pulled across the table. Have someone vary the resistance as the sensors move across the table. Rescale the graphs and examine them for “bad” data points. Repeat if necessary and print a graph for each group member. At the top of this graph write the title “Moving Tug-Of-War.”
Part I

Mass of friction block and force sensor = _____________ kg

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Static Friction Force (N)</th>
<th>Weight of Block and Sensor (N)</th>
<th>Normal Force (N)</th>
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</thead>
<tbody>
<tr>
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Free-Body Diagram

Part II

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<thead>
<tr>
<th>Trial</th>
<th>Height (m)</th>
<th>Length (m)</th>
<th>Track Angle (degrees)</th>
<th>$\mu_s$</th>
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</thead>
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</tbody>
</table>

Average: __________

Part III

Free-Body Diagram

Acceleration of the block and sensor = _______________ m/s$^2$

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Kinetic Friction Force (N)</th>
<th>Weight of Block and Sensor (N)</th>
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</table>
Part IV

<table>
<thead>
<tr>
<th>Trial</th>
<th>Surfaces</th>
<th>$F_a$ (N)</th>
<th>$m$ (kg)</th>
<th>$a$ (m/s$^2$)</th>
<th>$\mu_k$</th>
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<td>6</td>
<td>felt on table</td>
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</tbody>
</table>

Questions

Write answers for the following questions. Attach a separate sheet, if necessary.

1. In Part I, you used the force sensor to measure the applied force acting on the force sensor hook. This force was applied to the hook through the tension force of the string, and was caused by 0.105 kg of hanging mass. Calculate the weight of the hanging mass using $W = mg$, and compare this force to the applied force you measured. Are they the same? What does this imply about static tension forces in strings (even when the string changes direction over a pulley)?

2. In Part II, you measured $\mu_s$. Compare this to the value you measured for $\mu_k$ in Part IV for the wood side of the block. How do they compare?

3. Examine the results in your table for Part IV. Tell whether each of the following parameters had an effect on the value of the kinetic friction coefficient, $\mu_k$:
   - The magnitude of the applied force (and thus the acceleration of the sliding system).
   - The magnitude of the normal force.
   - The surface in contact with the table.

4. Do your graphs from Part V verify Newton’s Third Law? How? Did it make a difference whether the system was moving or not?
1. What two physical quantities will you measure for each cart in the collisions in Part I?

2. In Part II, which direction of motion will be measured as a positive velocity?

3. In Part II, which of the following velocities will be equal to zero: $v_1$, $v_2$, $v_1'$ and $v_2'$?

4. What will make the carts stick together for the “sticky collisions” in Part III?

5. What distinguishes Trial 5 from all the other trials in Part IV?
Lab 8: Newton’s Third Law and Conservation of Momentum

Objective: To investigate Newton’s Third Law as it applies to colliding objects and verify the Momentum Conservation Law.

Procedure

Part I: Forces and Collisions

1. Acquire two collision carts, three bar masses, a spring scale, two force sensors and two rubber bumpers. Use the small screwdriver to attach the force sensors to the carts. Place your kinematics track so it runs on the table beneath the computer at your lab station. Level the track.

2. Plug the force sensors into Analog Channels A and B. Open the Science Workshop file called “Force Sensor Collisions” in the Lab 8 folder inside Concordia Labs in the Phys-111 folder.

3. Double-click on the Channel A force sensor’s icon to open the force sensor setup window. Make sure that nothing is pulling on the force sensor’s hook and press the Tare button. You may need to zero the sensor periodically during this procedure. Make sure the High Value in the force sensor setup window says 0 and click <Read>. Then attach a 5-N spring scale to the force sensor. While you pull against the force sensor with a steady force of 2.0 N, enter the value +2 in the Low Value window and press <Read>. Repeat for the second force sensor, but this time enter a value of -2 in the Low Value window. Both force sensors are now calibrated, and the force sensor in Channel A will read a push as a negative (leftward) force while the other will read a push as a positive (rightward) force. Minimize the controller window.

4. Unscrew the hooks on the force sensors and replace them with rubber bumpers. Place the carts on the kinematics track about 40 cm apart and press Tare on both sensors. Make sure that Cart 1 (the one with its force sensor plugged into Channel A) is on the left. For the first trial, press REC and push the two carts so they coast toward each other and collide at approximately equal speeds in the center of the kinematics track. Press STOP. Rescale the graphs. Use the Magnifier tool to display the instant that the collision took place. Perform several magnifications if necessary to make the collision curve fill the display.

5. Drag rectangles around the part of your plots that show the instant of the collisions. In the statistics windows, the maximum value of the forces will be displayed (the y value), and so will the area under each curve (under “Integration”). This area is the total impulse during the collision, the product of the force and time on a moment-by-moment basis. Record these four values in the appropriate spaces on the Part I table.

6. For Trial 2, record a collision for Cart 2 at rest with Cart 1 moving toward it.

7. For Trial 3, record a collision for Cart 2 moving slowly away (to the right) from Cart 1 with Cart 1 overtaking and colliding with it.

8. For Trial 4, place two mass bars on Cart 1 and make it collide with the Cart 2 at rest.
Part II: Two Carts Springing Apart

1. Remove the force sensors from the collision carts. Return both force sensors.
   Acquire a plunger cart and two motion sensors. Use a hexagonal wrench to remove
   the bumper from the kinematics track. Plug the motion sensors into Digital Channels
   1 & 2 and 3 & 4 on the Science Workshop interface, with the yellow plugs in
   Channels 1 and 3. Set the motion sensors to the “narrow beam” setting. Clip the
   sensors into both ends of the kinematics track, with the motion sensor in Channels 1 &
   2 on the left. Open the Science Workshop file called “Two Motion Sensors” in the
   Lab 8 folder inside Concordia Labs in the Phys-111 folder.

2. Push the plunger completely into the plunger cart and slightly up to latch it. To
   release the plunger, set the cart on the track and gently tap the pin with a meter stick.
   Practice releasing the plunger so the meter stick doesn’t affect the motion of the carts.
   Place the collision cart right next to the plunger cart so that the plunger will push
   against this second cart when released as shown below. Now release the plunger for a
   practice run to make sure the carts move smoothly away from each other.

3. Put the carts back into their starting position, push REC and release the plunger.
   Catch the carts before they hit the motion sensors. Press STOP after you stop the
   carts. The d-t graphs of the two carts should be displayed on your computer screen.
   Complete the Part II table on your answer sheet for Trial 1, which quantitatively
   describes what has just happened. Use the electronic balance at the front of the room
   to measure the masses of the carts. In Parts II-IV of today’s lab, a prime (′) will be
   used to denote velocities and momenta after a collision has taken place, so \( v_1′ \) and
   \( v_2′ \) will be the velocities after the plunger has been released. Unprimed velocity and
   momentum variables describe the carts before the collision. In this part of the
   experiment, \( v_1, v_2, p_1 \) and \( p_2 \) are all equal to zero, and these zero values have been
   entered in the table. Measure the velocities of the carts by fitting a curve to a smooth
   portion of the d-t graph just after the plunger was released. The motion sensors have
   been configured so that they both read distances positive to the right, so record a
   negative value for \( v_1′ \) since it was travelling to the left and a positive value for \( v_2′ \).
   Calculate the momentum of each cart after the collision by multiplying the mass and
   velocity (note negative values) of the corresponding cart and then complete the last
   entry in the table by finding \( p_1′ + p_2′ \).

4. For Trial 2, repeat the procedure, but place a weight bar on each cart. Weigh the bar
   masses on the balance to obtain the total masses for the carts.

5. For Trial 3, repeat the procedure with 2 weight bars on Cart 1 and one weight bar on
   Cart 2. Measure the mass of the third weight bar and add the masses of the bars to
   obtain the total mass for the carts.
Part III: Sticky Collisions

1. In Part III, we will make momentum measurements for kinematic carts that stick together during collisions. We will use the Velcro circles on the carts to make them stick together when they collide.

2. Remove all mass bars from the carts. Push the plunger all the way in on the plunger cart and make the Velcro circles on the two carts face each other. Practice pushing Cart 1 so it coasts into the stationary second cart and sticks to it. Use REC and STOP to make a run that measures the motion of the carts. Curve-fit the graph from Motion Sensor 1 to measure the velocities before and after the collision and record in the Trial 1 row in the table for Part III. You can ignore the graph for Motion Sensor 2, since $v_1' = v_2'$. Find the momentum before and after by taking $p_1 = m_1 v_1$, $p_1' = m_1 v_1'$ and $p_2' = m_2 v_2'$. We expect the momentum of the system to be the same before and after the collision, since there were no external forces acting on the carts. Find a percent difference for the momenta before and after the collision, using

$$\% \text{ Dif.} = \left( \frac{p_1 + p_2}{p_1' + p_2'} \right) \times 100$$

and record in the table.

3. For Trial 2, repeat the procedure, but place one weight bar on each cart. Add the masses of the weight bars to obtain the total masses for the carts.

4. For Trial 3, repeat the procedure with 2 weight bars on Cart 1 and one weight bar on Cart 2. Add the masses of the weight bars to obtain the total mass for the carts.

Part IV: Springy Collisions

1. In Part III, we will make momentum measurements for kinematic carts that do not stick together during collisions. The collision carts have magnets mounted in their ends, which will cause them to have a “springy” collision without coming into physical contact.

2. Return the plunger cart and use your second collision cart for Cart 2. Place a bar mass on Cart 1. Practice pushing Cart 1 so it coasts into the stationary second cart and “collides” with it, without the carts touching each other. Use REC and STOP to make a run that measures the motion of the carts. Curve-fit the graph from Motion Sensor 1 to measure the velocities of Cart 1 before and after the collision and record in the Trial 1 row in the table for Part IV. Then curve-fit the graph from Motion Sensor 2 to measure the velocity of Cart 2 after the collision and record. Calculate the momentum values for both carts before and after the collision by multiplying the appropriate masses and velocities. Then calculate the value of the last column and record, using

$$\% \text{ Dif.} = \left( \frac{p_1 + p_2}{p_1' + p_2'} \right) \times 100$$

3. For Trial 2, repeat the procedure, but place a weight bar on Cart 2. Add the mass of the weight bar to obtain the total mass for Cart 2.

4. For Trial 3, repeat the procedure, but remove the weight bar from Cart 2 and place it on Cart 1. Add the mass of the weight bar to obtain the total mass for Cart 1.

5. For Trial 4, repeat the procedure with no bar masses on either cart.
6. For Trial 5, place two bar masses on Cart 2. Give Cart 2 a push so it coasts slowly to the right and push Cart 1 so it moves faster, overtaking and colliding with Cart 2.
7. Use the hexagonal wrench to replace the bumper on the kinematics track and return all materials.
Part I

<table>
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<th>Trial</th>
<th>$F_{max}$ A (N)</th>
<th>$F_{max}$ B (N)</th>
<th>Impulse A (N s)</th>
<th>Impulse B (N s)</th>
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Part II

<table>
<thead>
<tr>
<th>Trial</th>
<th>$m_1$ (kg)</th>
<th>$m_2$ (kg)</th>
<th>$v_1$ (m/s)</th>
<th>$v_1'$ (m/s)</th>
<th>$v_2$ (m/s)</th>
<th>$v_2'$ (m/s)</th>
<th>$p_1$ (kg m/s)</th>
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Part III

<table>
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<tr>
<th>Trial</th>
<th>$m_1$ (kg)</th>
<th>$m_2$ (kg)</th>
<th>$v_1$ (m/s)</th>
<th>$v_1'$ (m/s)</th>
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<th>$v_2'$ (m/s)</th>
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<th>$p_1'$ (kg m/s)</th>
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<th>$p_2'$ (kg m/s)</th>
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Part IV

<table>
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<tr>
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<th>$v_1'$ (m/s)</th>
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<th>$p_2'$ (kg m/s)</th>
<th>% Dif.</th>
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Questions
Write answers for the following questions. Attach a separate sheet, if necessary.

1. How close were your measured maximum force values for the two carts in your collisions in Part I? Comment on possible reasons for differences.
2. How close were your measured impulse values for the two carts in your collisions in Part I? Comment on possible reasons for differences.
3. In Part II, what values would you have obtained for the last column, $p_1' + p_2'$ in an ideal experiment? How close were your measured values? Comment on possible reasons for differences.
4. Compare the velocities you measured for the carts in Trial 3 of Part II. Use the Momentum Conservation Law to explain why these values are reasonable.
5. In Part III, what sorts of values did you obtain for the last column, the percent difference? Comment on possible sources of error.
6. In Part IV, what sorts of values did you obtain for the last column, the percent difference? Comment on possible sources of error.
7. A car with a mass of 850 kg travelling at a speed of 32 m/s collides head on with a 1400-kg truck travelling at a speed of 28 m/s. If the two vehicles stick together after the collision, what is their velocity (magnitude and direction)?
1. What safety equipment will we be using in this week’s lab?

2. In Part I, what device will be used to measure the time that the ball is in the air?

3. What is the box used for in Part II?

4. What range setting will be used for the projectile launcher in Part III?

5. When solving for time in Part IV, the quadratic formula generates two solutions. Which solution will be discarded?
Lab 9: Two-Dimensional Motion (Projectile Motion)

Objective: To investigate projectile motion.

Procedure

Part I: Time of Flight and Initial Velocity

1. Acquire a projectile launcher, c-clamp, meter stick, yellow ball, timing pad, extension cord, plumb-bob and safety glasses for everyone in your group. Connect two photogates to the clamp on the projectile launcher. Plug the first photogate that the ball will pass through into Digital Channel 1 and the second photogate into Digital Channel 2. Connect the timing pad to the extension cord and plug the extension cord into Digital Channel 3. Open the Science Workshop file called “Projectile” in the Lab 9 folder inside Concordia Labs in the Phys-111 folder.
2. Clamp the base of the projectile launcher to the edge of a lab table near your computer with the c-clamp. Aim the launcher away from the table toward the center of an open area at least 3 meters away. Don’t aim the launcher toward any other lab stations. Adjust the angle of the launcher to zero degrees so the plastic ball will be launched horizontally.
3. Put on your safety glasses before firing the launcher. Keep them on during the whole activity today.
4. Put the plastic ball into the projectile launcher. Cock the launcher to the short range position. Test fire the ball to determine where to place the timing pad on the floor. Put the timing pad on the floor where the ball hits.
5. Reload the ball into the projectile launcher and cock the launcher to the short range position. Click on REC and shoot the ball. After the ball hits the timing pad, click STOP. The first table on your computer displays the initial velocity of the ball as it left the launcher and the second table displays the time it took for the ball to travel from the second photogate to the timing pad. Record these values in the data table on your answer sheet.
6. For Trial 2, repeat the procedure with the ball cocked to the medium range position.
7. For Trial 3, repeat the procedure with the ball cocked to the long range position.
8. For Trial 4, repeat the procedure with the ball cocked to the short range position with the angle of the projectile launcher adjusted to 30° above the horizontal.
9. For Trial 5, repeat the procedure with the ball cocked to the medium range position with the angle of the projectile launcher adjusted to 30° above the horizontal.
10. For Trial 6, repeat the procedure with the ball cocked to the long range position with the angle of the projectile launcher adjusted to 30° above the horizontal.
Part II: Projectile Range vs. Angle

1. Acquire some blank sheets of paper, a piece of carbon paper and a box to serve as a landing pad on the same level as the launcher, as illustrated in the following diagram.

![Diagram of projectile launcher and box](image)

2. Adjust the angle of the projectile launcher to ten degrees. Put the plastic ball into the projectile launcher and cock it to its medium range position. Fire some shots to determine where the ball will hit. Place the box so the ball will land in the middle of its top. Tape a piece of white paper to the top of the box. Place a piece of carbon paper (carbon-side down) on top of this paper and tape it down. When the ball hits the box, it will leave a mark on the white paper.

3. Measure the horizontal distance from the center of the ball as it leaves the launcher (it’s marked on the launcher) to the leading edge of the paper and record this distance in meters, to the nearest millimeter, in your table in the Paper Dist. row for 10°.

4. Fire three shots. Remove the paper from the box and measure the distance from the leading edge of the paper to each of the three dots and record as the three trials in the appropriate column in the table. Record values in meters to the nearest millimeter. Calculate the average for the three trials and record in the table. Add this average to the distance to the paper and record in the last row of the column.

5. Use fresh pieces of paper and repeat this procedure in ten degree increments up to 80 degrees and record all values in the table.

6. Make a graph of the projectile range vs. sin 2θ. Run Vernier Graphical Analysis. In the data table, change the X label to T with units of degrees, and change the Y label to Range with units of m. Enter the Total Dist. values from your Part II table into the Range column. Enter the corresponding launch angles into the T column. Pull down the Data menu and select New Column. Change the label of this column from X to =sin(2*T). This entry is case-sensitive and must be entered exactly like you entered the label in the first column. On the graph that is displayed, click on the label on the horizontal axis. A menu will appear. Select =sin(2*T). A new graph will now be plotted. Now pull down the Analyze menu and select Automatic Curve Fit... Click the Linear button. Click <OK>. Pull down the File menu to Print Graph...and print a copy of this graph for everyone in your group. Write the equation of the fitted line in the space provided on your answer sheet in the form Range = A + B sin 2θ.
7. Given that the horizontal and vertical components of the ball’s velocity are independent of each other, it can be shown that the ball’s range is given by 

\[ R = \frac{v_o^2 \sin \theta}{g} \]

where \( R \) is the range of the projectile, \( v_o \) is the launch velocity, \( \theta \) is the launch angle, and \( g \) is the acceleration of gravity, 9.8 m/s\(^2\). Take \( v_o \) to be the initial velocity measured in Trial 5 of Part I and calculate the expected range for each launch angle in Part II. Record these values in the row labeled \( \text{Calc. Dist.} \) in the Part II table.

**Part III: Hitting the Target**

1. Move the box so that it is somewhere within the range of the launcher for the medium range setting. Measure the horizontal distance from the launch point to the middle of the box. Record this as the Target Range for Trials 1 and 2 in the table on the answer sheet.

2. If we solve the range equation for the launch angle, we get 

\[ \sin^{-1}\left(\frac{Rg}{v_o^2}\right) \]

Using the target range and \( v \) from before, solve this equation and record this as \( \theta \) for the first trial on the answer sheet. Then fire the ball at that launch angle so that it lands on carbon paper over white paper. Measure the actual horizontal distance the ball traveled and record on the answer sheet.

3. There is a second launch angle that will also hit the target. Looking at your data from Part II, see if you can find that angle. Ask a lab assistant for help if necessary. Then fire the ball at that angle and measure its range and record. Record the second angle and actual range on the answer sheet.

**Part IV: Range to the Floor**

1. Once again, aim the launcher so the ball will land on the floor. We will now use the launch velocity and launch angle to predict the horizontal range of the ball as it lands on the floor. Adjust the angle of the projectile launcher to an angle between 30 and 60 degrees and record this angle in the space provided.

2. Put the plastic ball in the projectile launcher and cock it to the medium range position. Press \textbf{REC} and fire the ball. Press \textbf{STOP}. Record the launch speed of the ball in the space for \( v_o \) on the answer sheet.

3. Use the plumb-bob to measure the distance from the bottom of the ball at launch (marked on the launcher) to the floor and record as \( y_o \).

4. When a projectile is launched at an angle, its velocity can be resolved into horizontal and vertical components as illustrated in the following diagram.
5. As a projectile flies through the air, the equation for its vertical position is
\[ y = y_o + (v_o \sin \theta) t - \frac{1}{2} gt^2. \]
The equation for its horizontal position is
\[ x = v_o \cos \theta \cdot t. \]
In order to predict the horizontal range \( x \), it is necessary to solve the vertical position equation for the time when the ball strikes the floor, \( t_f \). If we define the position of the floor to be \( y_f = 0 \), the vertical position equation can be re-arranged into standard form as
\[ \frac{1}{2} gt_f^2 - (v_o \sin \theta) t_f - y_o = 0. \]
This equation is quadratic in \( t_f \) and the solution can be obtained with the quadratic formula. Solving for \( t_f \) and discarding the negative solution, we obtain
\[ t_f = \frac{v_o \sin \theta + \sqrt{(v_o \sin \theta)^2 + 2gy_o}}{g}. \]

6. Calculate \( t_f \) and record on the answer sheet. Then use the horizontal position equation to calculate the predicted range and record. At time \( t_f \), the equation becomes
\[ \text{Predicted range} = x_f = v_o \cos \theta \cdot t_f. \]

7. Launch the ball so that it lands on carbon paper over white paper. Measure the distance from the launch position to the landing spot and record as the actual range.
Phys-111 Lab 9
Answer Sheet

Part I

<table>
<thead>
<tr>
<th>Trial</th>
<th>Angle</th>
<th>Range</th>
<th>Initial Velocity (m/s)</th>
<th>Time of Flight (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0°</td>
<td>short</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0°</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0°</td>
<td>long</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30°</td>
<td>short</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>30°</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>30°</td>
<td>long</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Part II

<table>
<thead>
<tr>
<th>Trial</th>
<th>10°</th>
<th>20°</th>
<th>30°</th>
<th>40°</th>
<th>50°</th>
<th>60°</th>
<th>70°</th>
<th>80°</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Paper Dist.
Total Dist.
Calc. Dist.

Equation of fitted line:

Part III

<table>
<thead>
<tr>
<th>Trial</th>
<th>θ</th>
<th>Target Range (m)</th>
<th>Actual Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part IV

\( \theta = \) \hspace{1cm} \( v_0 = \) \hspace{1cm} m/s

\( y_0 = \) \hspace{1cm} m \hspace{1cm} Calculated \( t_f = \) \hspace{1cm} s

Predicted range: \hspace{1cm} m \hspace{1cm} Actual Range: \hspace{1cm} m

Questions

Write answers for the following questions. Attach a separate sheet, if necessary.

1. In Part I, how do the values for the time of flight for the short, middle and long range distances compare when the ball was launched horizontally?

2. In Part I, how do the values for the time of flight for the short, middle and long range distances compare when the ball was launched at 30° above horizontal?

3. What is peculiar about some of the \( x \)-values of the points in your graph for Part II? Try to give a mathematical explanation for this “pairing” that you observe.

4. Look at the value of the Mean Square Error on the graph. This value describes how well the fitted line matches the points on the graph. The closer the mean square error is to zero, the better the fit. Report this value. Does it indicate that your measured data agrees with the range equation?

5. The equation of the line fitted in your graph is of the form \( \text{Range} = A + B \sin \theta \).

The range equation can be written as \( R = \left( \frac{v_0^2}{g} \right) \sin 2\theta \), so \( B \), the slope of the line, should be equal to \( \frac{v_0^2}{g} \) and \( g = \frac{v_0^2}{B} \). Calculate \( g \) and find the percent error for this measurement, using \( \% \text{error} = \frac{g_{\text{measured}} - 9.80}{9.80} \times 100 \).

6. What units does the slope of your graph have? What units does \( \frac{v_0^2}{B} \) have?

7. In Part III, how close did the ball land to the target range in the two trials? Give some possible reasons for any error.

8. Calculate the percent difference between the predicted range and actual range in Part IV. Use the equation \( \% \text{ Dif.} = \frac{\text{Predicted} - \text{Actual}}{\text{Actual}} \times 100 \).
APPENDIX C

Review Panel Instructions
**Instructions for Review Panel**

In this quasi-experiment, the Phys-111 class at Concordia will be divided into two lab sections. One of the sections will participate in Interactive Engagement labs, as found in RealTime Physics. The other will use lab exercises written by me, which are meant to be Traditional labs that cover the same concepts and use MBL equipment, but are written with cookbook procedures.

I think that any physics teacher knows what is meant by “cookbook,” and I want to make sure that these procedures will match these characteristics. Your goal is to verify the following:

- Each lab matches the conceptual content of the corresponding RealTime Physics exercises, Labs 1-7, 9, and 10. If you need a copy of the RealTime Physics workbook, please let me know and I will give you one.
- The labs should follow old-fashioned cookbook procedures.
- The labs should take about two hours, including time to answer the questions at the end of the procedure.
- Offer any suggestions you might have about the clarity and practicality of the procedures.
- Feel free to offer any corrections in language, spelling, etc.

In my proposal, I wrote definitions for the two types of procedures:

<table>
<thead>
<tr>
<th><strong>IE Group</strong></th>
<th><strong>Traditional Group</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory procedures that actively engage the learner by the use of meaningful questions integrated into the procedure, cooperative MBL activities, and an emphasis on concept formation.</td>
<td>Laboratory procedures that follow a &quot;cookbook&quot; approach, providing verbose detailed instructions with no reflective questions integrated into the experimental procedure, &quot;fill-in-the-blank&quot; data tables, and specific questions that occur after the exercise is completed.</td>
</tr>
</tbody>
</table>

To help guide your thinking, here are my two quantitative research questions, along with relevant quotes from the research literature:
<table>
<thead>
<tr>
<th>Proposal</th>
<th>Articles in AJP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RQ1</strong></td>
<td>Are there significant differences in the amount of conceptual mechanics knowledge gain for students who participate in active-learning MBL physics laboratories, compared to students who participate in equal-time exercises with traditional procedures that also make use of MBL equipment?</td>
</tr>
<tr>
<td><strong>RQ2</strong></td>
<td>Can the use of interactive-engagement laboratories in an otherwise traditional classroom environment produce significant gains in conceptual learning?</td>
</tr>
</tbody>
</table>

You will be helping me design the tools I will use to answer Research Question 1. Research Question 2 will only depend on the implementation of the exercises in the IE group, as found in RealTime Physics.

If you would like to see a copy of the full research proposal, it can be found at:
http://seward.cune.edu/~brr4974/papers/PROPOSAL_11_05_00.PDF

You can communicate your evaluations to me in any way that is comfortable for you. If you would like to mark a hard copy of the labs, I will be glad to pick them up. You can also make electronic comments on MS Word files for the labs or type your comments in an email message. Send all electronic correspondence to brent@royuk.com.

Thank you very much!
APPENDIX D

Instructor’s Feedback
Traditional and Interactive Engagement (IE) Lab Thoughts:

Lab 1: Position – Time Graphs

Traditional:

Part I: Students didn’t seem to have any idea why they were doing this section. The idea seems to be that using different sized parts of the “picket fence” still give the same speed, but the students aren’t familiar enough with the detectors to know what ‘s going on with them. So they just push the carts and write down numbers.

Part II: This section works pretty well; it gives them the feeling for how their motion affects the graphs. Calculating the slope of the last graph was fairly useless though, because it didn’t relate to anything. Most students only got this far through the lab.

Part III: This section was okay for the one group who got to it.

Part IV: No one made it to this section.

Part V: No one made it to this section.

Generally, the various parts seem disjointed – from carts to people to carts to people. The students got a lot out of Part II, but Part I took so long that they couldn’t get past the second section. For most people, this lab basically consisted of Part II.

IE

The Science Workshop file for Activity 1-1 (L1A1-1) had a bug, that the motion sensor either wouldn’t work at all, or would take from 20 seconds to several minutes to begin working. Closing the file, opening a new experiment and configuring it solved the problem.

Generally the lab worked well. The graph matching activities (L1A1-2, L1A2-2) were slightly confusing because the graphs in the book did not match the ones on the computer. Since some of the questions referred directly to the motion in the lab book, this caused some confusion.

Several students were unable to correctly answer Question 2-1 (Activity 2-1), about how slow versus fast motion showed up on the graph. They correctly described the difference between slow and fast motion, but not how it showed up on the graph as the distance from the time axis. This seemed to be the concept that the students had the most difficulty with here – the difference between velocity being the slope of a position graph, and being the value of a velocity graph.

Most students made it through Activity 3-3; a few only made it through Activity 2-2.

Lab 2: Changing Motion

Traditional:

This lab worked out well; most students finished the whole lab. Once the students understood the directions defined by the motion sensor, they were able to work with the graphs. The fact that the lab was short enough to complete in the time available meant that there was time to work with students on the meaning of motion graphs, and to compare position, velocity and acceleration graphs. This provided an important connection to lecture, and a good learning opportunity.

IE:

This lab worked fairly well. Most students did not finish, but most did get at least through Activity 3-1 or 3-2. Much of the time was spent becoming familiar with the software and
how to analyze graphs, and a lot of time was spent on understanding the graphs, which was good. I did Extension 2-3 “Using Statistics” with most groups individually, so that they would learn how to find velocities and accelerations from the means and slopes of graphs. As expected, velocity graphs were difficult for the students after becoming familiar with how position graphs worked, but since that was the point of the lab it was good that the students spent the most time understanding that.

Lab 3: Force and Motion

Traditional:
No one made it past Part II; some never made it past Part II #7. Part III, if anyone had gotten there, seems to be missing a Step 5: Fit a line to the graph. Record the slope as the mass of cart & sensor (slope). It should also have a Step 6: Calculate the percent difference between the two values for mass.
Part I seemed to take a long time (30 – 45 minutes) for a section that didn’t seem to explore any deep physical concepts. The idea that the regression line was a model for the data didn’t seem to be universally understood, especially the meaning of the intercept. In Part II, Step 10, students were very confused about why they were measuring the force on a cart that wasn’t moving.
Generally the lab went well (as far as students made it). They did gain some understanding of modeling data with an equation. However, since so much time was spent in Part I at the expense of Part III, they didn’t gain much new understanding of the relationship between force and acceleration.

IE:
I did Activity 1-4 with the students as a group to start the lab, since the calibration in the book is very different from the actual method they need to use. They made it through the lab pretty well; some made it all the way through.
The big problem with the lab was the calibration of the force sensors. Between Activities 2-2, 2-3 and the run with another mass to fill out Table 2-3, the calibration would sometimes change, so that the results were rather random. Also, the experiment files have a calibration that gives a result of acceleration being proportional to the negative of force. So we had to change the calibration to a low value of 2 N and a high value of 0 N. Since the point of the lab is the (positive) proportionality between force and acceleration, this was a bit of a problem.

Lab 4: Combining Forces

Traditional:
No one made it past Part II, so there never really was a combining of forces. Most of the acceleration versus force graphs came out well, so they did at least see that force and acceleration are proportional.

IE:
There were some calibration problems again, so that sometimes force and acceleration had opposite signs. Fortunately the people who had this happen to them noticed that it was wrong, so they learned something. Activity 2-1, where they hook a spring scale to a cart and pull it with constant force, was nearly impossible on our tracks. The part with two spring scales was
impossible, and impossible to compare to one spring at twice the force. Only one group made it through Activity 3; one group only made it through Activity 1. Most made it partway through Activity 2. But they did seem to get the idea that force and acceleration are in the same direction, and are related in their sizes.

**Lab 5: Force, Mass and Acceleration**

**Traditional:**

This lab worked fairly well; most groups were able to finish. For some groups the graph of a vs m was not really an inverse, but most graphs of a vs 1/m were fairly good. Some of the fitted lines had non-zero intercepts which the students had a hard time understanding.

**IE:**

All students made it through this lab, which made them feel better about it. Several students’ data lead to acceleration vs mass graphs that were linearly proportional rather than inversely proportional. This of course caused confusion for them and for me, since I could see nothing they did wrong. Investigation 2 did not go as well; the ratio F/a did not always equal the measured mass. Activities 2-2 and 2-3 were not real interesting for the students, as we had already covered Newton’s second law in lecture, and they were happy to simply apply that rather than using their investigations to discover it again.

**Lab 6: Gravitational Forces**

**Traditional:**

Somehow this lab took a lot longer than it seemed like it would. Amazingly, even the picket fence part took some students a long time. Most made it through Part VI, but no one made it through Part VII. Sign problems were a problem for this lab, with the students becoming used to the direction of motion in Parts II and III, which then changed in Part IV. Most of the calculations of g worked out pretty well, even in Part VI. Unfortunately the students were rather rushed through Part VI (I told them to try to get through that section), so they were unable to spend the time they needed to understand what it was really getting at.

**IE:**

This lab started out well and lost focus toward the end. Investigation 1 was a good review of motion graphs, which students had begun to forget (since we’d already had a test over them). The value of the acceleration due to gravity came out well, and all was good. It would have been nice to do Extension 1-4, since those activities were done in the traditional lab. Investigation 2 did not go so well. The students did not understand the idea that they were trying to “discover” gravity; they seemed to think they’d already noticed gravity before. They did not understand that gravity is an “invisible” force and that the force of gravity is a model we use to explain why things fall. The questions at the beginning of Activity 2-1 were just confusing, since they had no idea what it meant to “invent” gravity, and the questions were worded in a confusing way. The questions in Activities 2-2 and 2-3 really seemed to have little relationship to anything else done in the lab, which suited the students fine because they did relate to things done in class that the students remembered how to do. Investigation 3 seemed unrelated to the rest of the lab, and most of the students who actually got that far (about half) thought it rather goofy. They had no idea of what was meant by a mechanism for an object to apply a normal force, and they
seemed surprised that after adamantly focusing on observable quantities the lab book would suddenly expect them to think in terms of microscopic mechanisms (without “inventing” them).

Lab 7: Passive Forces and Newton’s Laws

Traditional

The lab was a good length; everyone made it through the whole lab. This was a good review of forces and vector diagrams, things that had been done several weeks ago in lecture. Most students were able to remember these concepts, although it would have been nice to have them derive the formulas for the coefficients of static and kinetic friction themselves. Some of the students did not work through the given derivations sufficiently to really understand why the various terms were in them. The analysis of kinetic friction was made more difficult by the fact that the derivations of kinetic friction force and the coefficient of kinetic friction (in Parts III and IV) are wrong. Since both masses are moving, the mass in Newton’s second law is the mass of both the block/sensor and the hanging mass. So the value of “m” in the expression for \( f_k \) in Part III should be the mass of both masses. In the expression for \( \mu_k \) in Part IV, the “m” in the numerator should be the sum of the masses, while the “m” in the denominator should be the mass of the hanging mass. Since the hanging mass changed in Part IV, Step 4, the results gave the impression that the coefficient of friction depended on speed.

IE

This lab was a little long. Most students made it into Investigation 3, although no one made it past Activity 3-2. Some students did not make it past Activity 2-1. Again in this lab, the students did not understand the idea or the need for “inventing” forces (as in the gravity lab). Questions 1-4 and 1-5, which are the summary points of Investigation 1, ask the students to “invent” friction as a means of “saving” Newton’s second law. This is confusing, however, since the idea of a frictional force has been used since the first page of the lab (and extensively in lecture). So the students (understandably) do not understand the need to invent something they’ve already been using, and Questions 1-4 and 1-5, rather than summarizing and clarifying the investigation, simply confuse the students and bring the lab to a grinding halt. Investigation 1 is already difficult and confusing in itself, without the “invention” problem. It is very difficult to achieve constant velocity with the friction pads, so we’re forced to try different amounts of friction, and assume that somewhere in that range there will be a value of friction that actually achieves zero acceleration. It is also confusing to the students that the force measured by the force sensor is less while the cart is moving (accelerating) than while at rest, even though the same applied force (the weight hanging on the string) acts. Unfortunately this point is never addressed in the Investigation. The students notice this effect, however, and are expecting to analyze that problem when they’re confronted by the “invention” questions, and this adds to the confusion.

Investigation 2 works fairly well, in that the students can see Newton’s third law working. However the skateboards have such poor bearings that it takes more than 50 N to pull even the lightest people on them, so they cannot really see Newton’s third law at work with the skateboards. In Investigation 3, the students have great difficulty with questions like Question 3-2, which ask about a mechanism for explaining the transmission of tension along a rubber band. This question asks for an answer so far removed from what they’ve been thinking about and working with in the lab that few if any students are able to even understand the question without a lot of help, and the question feels rather unfair to students who think that their investigations
should help them answer the questions. No one has been able to think about a microscopic mechanism without a lot of direction.

Lab 8: Newton’s Third Law and Conservation of Momentum

Traditional:
Most students made it through Part III, some finished this lab. Surprisingly, some force sensors show a marked “bounce” after impact while others do not. So some graphs of Force versus Time were not very similar. Trading sensors around till students had matching sensors helped a lot. In general the lab went well, with Newton’s third law being pretty obvious in Part I and momentum being conserved fairly well throughout.

IE:
There was a software problem in this lab. The “Collisions L9A1-1” experiment was set to start taking data when a force sensor activated. The problem, however, was that it took a fairly large force to activate the data recording, so initially all they saw was the very end of the force being exerted, and maybe the bounce. So I removed all start and stop conditions. The instructions are vague and irritating on the aspect of calibration – they say to calibrate and give enough instructions about it to confuse the students but not enough to actually explain how to calibrate. They mention here (and in other labs) to hang a 1-kg mass from the force sensor to calibrate it. Naturally this confuses students who know how we normally calibrate the sensors with spring scales, but who feel compelled to follow every instruction in the manual. So I discover groups taping masses to their force sensors (which they had previously calibrated with spring scales).

This lab actually went very fast, and most students finished a half hour early. I wish the lab had done more collisions and had the students calculate more momenta. There was no reason not to, and it would have made the lab more similar to the traditional lab. Using one inelastic collision to verify momentum conservation seems rather sparse.

Lab 9 (10): Two-Dimensional Motion

Traditional
The students had a lot of fun with the projectile motion launchers in this lab. Unfortunately no one was able to finish the lab. Most students made it only partway through Part II. In Part II it was very difficult to see the marks made by the ball on the low angle, and the differences among the Average distance, Paper distance and Total distance confused several students. As in a lot of these labs, it would have been nice to put the range equation near the beginning of the section, to tell the students where they are going, rather than at the end of the section to tell them what they were supposed to get. As it was the students converted their graphs of range versus angle to range versus the sine of twice the angle without knowing why they were doing it. I would have preferred doing Part IV before Parts II and III, since this was closer to what we’d been doing in class. This is definitely a lab that would have been more beneficial had they gotten farther through it.
IE:

This lab was a pretty good length; everybody finished. The motion graphs at the beginning were a good review, although a discouraging number of students had forgotten how graphs looked for accelerated motion. It would have been nice to put this lab in before the labs on forces—it would have provided a good lab on projectile motion while we were doing it in class. The students were surprised that all of a sudden there were a lot of calculations to do, since these labs had generally avoided calculations in all other labs. The students had problems keeping a consistent “tapping” going to accomplish good two-dimensional motion. The resulting motion usually ended up looking a lot like projectile motion, but the graphs were not well fit by a parabola. It would have been nice to have a little more discussion or analysis of the results; it seemed for the first time in this lab book that the students simply took data, analyzed it with some calculations, and finished.

Overall Thoughts:

When I first taught these labs in the spring of 2001, the students in the traditional lab definitely expressed to me more positive opinions of the labs than students in the IE labs. This seemed to be because students in the traditional labs could at least tell what concepts they were working on, even if they couldn’t finish the lab, while students in the IE labs often had no idea what they were doing or what they were supposed to get from the lab if they couldn’t finish it. In the fall of 2001, neither lab expressed strong positive or negative opinions of the labs. The IE lab group did seem to react strongly to “inventing” forces and mechanisms; they did not seem to like this practice.

In thinking about the labs, it seems that there are two ways to approach a physics laboratory experience: One way is to prepare a set of experiences that the student can work through to come to an understanding of a concept, the other way is to try to model the process of doing physics by designing an experiment, calibrating measuring devices, taking and analyzing data and coming up with a conclusion. The IE labs clearly approached lab in the first way, while traditional labs generally approach it in the second way. Either way can be useful to the student, but the IE labs would have been more effective, I think, if the students had a more clear idea going into the lab what concepts they were trying to work with, and if they could be sure to finish the process. As it was, the IE labs often felt like a set of rather unconnected experiences, which the students would hopefully put together into one conceptual framework. There was no well-defined beginning, middle and end; there were only as many experiences as the student could get through in two hours. The transitions between exercises within a lab made sense to me, but the students never noticed them and often asked about what they were doing and why.

The traditional labs also suffered from this problem, but even more so. Traditional labs usually have a beginning (deriving some equation, designing an experimental set-up, calibrating the instruments) a middle (taking data, analyzing it in graphs and/or equations, coming up with a result) and an end (calculating errors or uncertainties, writing conclusions). These traditional labs had no such parts. They were simply the IE labs without the connecting prose and questions, so there was even less to guide the student through the lab and show why they were doing what they were doing. In some cases this lack of excess verbiage actually helped the students see the “big picture” of what they were doing, but in my opinion it did not make these labs “traditional”.

To use the IE labs effectively, I think that the instructor needs to be able to vary the way time is spent in lab and in lecture. Instead of having one two-hour lab each week and three lectures, an effective use of time would be to spend one whole week doing several of the labs, and then a few weeks without doing any labs. As it is, if the lectures continue at their normal pace,
the students are well past the concepts covered in many of the labs by the time that they do the lab, and the exercises seem like a tedious chore to develop something that the students are already familiar with. On the other hand, if the lectures keep pace with the labs, then the amount of material covered must change dramatically. It may be nice to spend three weeks developing Newton’s Second Law and over five weeks with forces, but this is at the expense of a good coverage of momentum, and all mention of rotations, torque, and oscillations. To say that IE labs do a great job of teaching forces is not really fair, since I could produce students expert at almost any topic if I spent five weeks on it. I think that to really use the IE labs effectively, the instructor must be able to modify the class schedule and spend more time in lab some weeks and less other weeks. The three lab series on Newton’s Second Law would be much more effective if it was done all in one week, instead of lectures. This way the students could develop a conceptual understanding of Newton’s Second Law in a coherent way, and not have it interrupted by the intervening weeks and the lectures in between. After the series on Newton’s Second Law, then the labs could be replaced by problem solving sessions involving forces.

Since the IE labs spend so much time on the conceptual basis for Newton’s Second Law, it is not surprising to me that the students would do well on the FCI after doing the labs. I have the feeling that they paid for this by being less able to do calculations and problems in the other ten chapters of the book we covered. The IE labs almost seemed written with the FCI in mind. Since the traditional labs did not have the conceptual emphasis to them that the IE labs did, it is not particularly surprising to me that students in those labs would improve less on the FCI. Unfortunately, since the traditional labs still covered the same topics as the IE labs and did not cover the concepts missed by the IE labs, the students did not get the benefit of practice with calculations for the topics missed by the IE labs. So the experiment seems a little biased toward improving the FCI scores of students in the IE labs.

In future versions of this experiment, I would like to see real traditional labs compared to the IE labs. And a more fair way to compare, I believe, would be to use the FCI as well as a quantitative test that emphasized problem solving and calculations. With the importance of calculations and problem solving in physics, this would seem a more complete test of how well the labs helped the students to learn physics. I would also suggest that since physics is much more than forces, comparison tests between traditional and IE labs should contain more topics than what is covered in the FCI.

I think overall that an ideal lab situation would make use of both types of lab. Some concepts, like Newton’s Second Law, need a lot of hands on time to develop a conceptual understanding, while the traditional way of approaching this concept in lab involves a lot of tedious calculations that do not seem to help the students’ conceptual or quantitative understanding. Traditional labs, however, could better cover other topics, and I think the students can gain from the traditional approach of modeling the way physics is done in the lab. If I was to use the IE labs in my own lab, I would probably mix them in with traditional labs, and modify the time I spend with them if possible.
APPENDIX E

IRB Documents
Interactive-Engagement vs. Traditional Laboratory Procedures in MBL Mechanics Exercises

IRB Research Proposal: Expedited

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1. Significance of the Project

Microcomputer-based laboratory (MBL) equipment has become very popular in the educational physics laboratory during the past ten years. Many research studies have been conducted in which MBLs have been used as one of several instructional methods, in which high conceptual learning gains have been attained.

Modern MBL laboratory procedures are characterized not only by the use of computer-interfaced equipment, but also by active-learning strategies that require the students to think and respond as the experiment is conducted. This is a change from traditional laboratories that have a “cookbook” flavor, merely giving instructions while calling for very little reflection until the end of the exercise. The two main research questions in this project will be:

RQ1. Are there significant differences in the amount of conceptual mechanics knowledge gain for students who participate in active-learning MBL physics laboratories, compared to students who participate in equal-time exercises with traditional procedures that also make use of MBL equipment?
RQ2. Can the use of interactive-engagement laboratories in an otherwise traditional classroom environment produce significant gains in conceptual learning?

This study will provide a quantitative argument about the effectiveness of active learning procedures in the introductory physics laboratory while holding constant as many other factors as possible. This will provide individual physics instructors with more information upon which to make decisions about the nature of the laboratory exercises they provide for their students.

2. Methods and Procedures

Students who enroll in Phys-111, General Physics I, at Concordia University enroll into one of two lab sections. One section will participate in MBL exercises written with traditional procedures, while the other will participate in the interactive-engagement exercises found in the popular lab series, Realtime Physics. Treatment will be randomly assigned to the two groups.

Each group will take a pretest of knowledge about force and motion known as the Force Concept Inventory (see attached). Both groups will participate in exercises of equal length, and will complete the same amount of assigned work. They will each have the same lab instructor. After the exercises are completed, all students will take the Force Concept Inventory as a posttest. Results will be analyzed in order to answer the research questions.

In addition to the measure of conceptual knowledge, students will be asked to fill out a Student Satisfaction Survey (see attached), to provide supporting information of a qualitative nature.

The study will last for nine weeks, January through March, 2001.
3. Participant Population

The population for this sample will be undergraduate students enrolled in introductory physics courses. This population will be restricted to a sample of approximately 30 students, who will enroll in Phys-111, General Physics I, at Concordia University in Seward, Nebraska during the Spring term of 2001. The course will be taught by Dr. Robert Hermann.

It is possible that some of the students in this course may be younger than age 19. Parental permission will be obtained if any students of this age enroll in the course (see attached letter).

4. Benefits and Risks to Participants

It is possible that there will be different learning gains for the two groups. The traditional group will be participating in exercises that are very similar to those presently in use at Concordia University.

Care will be taken to ensure that both groups do an equal amount of work. The instructor will assign grades to students based on their performance on material that is covered in the lecture portion of the course, which is identical for both groups. Each lab group will be evaluated according to the procedure they participate in, so lab grades will not be effected by individual’s treatment group.
5. Recruiting

The sample will be restricted to those who enroll in Phys-111 in the Spring, 2001 term, and consent to participate in the study.

6. Compensation

No compensation will be provided to the participants.

7. Informed Consent

See attached.

8. Methods for Informed Consent

The Informed Consent Letter will be presented to students in Phys-111 on the first day of class. Each student will be asked to read the letter and sign it if they agree to participate in the study. If any students who are under the age of 19 enroll in the course, permission of their parents will be obtained.

9. Maintaining Confidentiality

Students in the study will be assigned an identification number. All instruments delivered to the students will be labeled only with this number. The list of numbers will be kept in a locked office, room 113 of the Science Building at Concordia University. Immediately after the delivery of the student opinion survey, the list will be destroyed.
Dear Physics Student:

You are invited to participate in a research study that will be conducted during this term of Phys-111. The purpose of this study is to investigate the effectiveness of two different types of laboratory procedures, for introductory physics students like you. The title of the study is Interactive-Engagement vs. Traditional Laboratory Procedures in MBL Mechanics Exercises. If you are under the age of 19, permission will need to have been obtained from your parents.

During the first nine labs of Phys-111, the two lab sections will participate in laboratory exercises that use similar activities but different procedures. Both sections will meet in SC-215. One section will use exercises very much like those used in this course in recent semesters, and the other will use exercises from the commercial lab series, Realtime Physics. You will be asked to take a test of mechanics knowledge before and after you participate in the exercises, and an opinion survey at the conclusion of the study. No information pertaining to the grades you receive in this course will be used in the study, and Prof. Royuk will not participate in the teaching or evaluation of this course.

Each lab group will do a roughly equal amount of work. You will all be asked to complete a pre-lab worksheet and a post-lab homework assignment for each lab. No other post-lab writeup will be required. Any writeup that is done during the exercises will be turned in at the end of the period.

All students will conduct the lab exercises in order to learn physics. It is possible that you may learn more effectively because of your participation in one group or the other. Since you will be evaluated in each lab according to the procedure it uses, your grade in Phys-111 should not be affected if you learn physics better because of the lab section you are in.

Results from this study will be of interest to educational researchers who are investigating the effectiveness of various instructional techniques in introductory physics courses. The nature of the procedures in which your lab section participates has not yet been determined. A coin will be flipped to make this decision.

Your identity will be kept confidential in this project. The tests and survey you take will be marked with an identification number so that results can be tracked for each individual. The list of names and identification numbers will be kept locked in Prof. Royuk’s office during the study and will be destroyed immediately after the final survey.
is taken. Results of this study may be published in research journals or shared at conferences, and will hopefully be published in a doctoral dissertation, but no participants will be identified in any of these publications.

You will not be paid or compensated in any way for participating in this study.

If you have any questions about this study, please contact Prof. Royuk at 643-7496 or email broyuk@seward.cune.edu. You can also contact the advisor for this project, Dr. David Brooks, at (402) 472-2018, or dbrooks1@unl.edu. If you have any questions about your rights as a research participant that have not been answered by Prof. Royuk, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Participation in this study is voluntary. You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators, Concordia University, or the University of Nebraska. Your decision will not result in any loss of benefits to which you are otherwise entitled. If you do not participate in the study, the reader who evaluates your lab assignments will not know that you have opted out.

If you are interested in receiving a summary of the results of this study, please contact Prof. Royuk after the study is completed.

By signing below, you will indicate that you have read and understood this letter, and have decided to participate in this research project. You will be given a copy of this letter for your records.

Thank you very much,

Brent Royuk, Principal Investigator
Dr. David Brooks, Secondary Investigator

Signature of Research Participant ______________________ Date ______________________
December 21, 2000

Mr. Brent Royuk
800 No. Columbia
Seward NE 68434

Dear Mr. Royuk:

IRB # 2000-12-108 EX

TITLE OF PROPOSAL: Interactive-Engagement vs. Traditional Laboratory Procedures in MBL Mechanics Exercises

This letter is to officially notify you of the approval of your project by the Institutional Review Board for the Protection of Human Subjects. This project has been approved by the Unit Review Committee from your college and sent to the IRB. It is the committee’s opinion that you have provided adequate safeguards for the rights and welfare of the subjects in this study. Your proposal seems to be in compliance with DHHS Regulations for the Protection of Human Subjects (45 CFR 46) and has been classified as exempt.

1. Please include the assigned and approved IRB number on all informed consent forms.

This project should be conducted in full accordance with all applicable sections of the IRB Guidelines and you should notify the IRB immediately of any proposed changes that may affect the exempt status of your research project.

Sincerely,

Sharon Evans, Chair
for the IRB

xc: Dr. Donald Helmuth
    Faculty Advisor
    Unit Review Committee