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Evaluating Factors Contributing to Engineering Technology Students' Introductory Physics Experience

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EVALUATING FACTORS CONTRIBUTING TO ENGINEERING TECHNOLOGY STUDENTS' INTRODUCTORY PHYSICS EXPERIENCE

By

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B.S. Worcester Polytechnic Institute, 2003

A THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
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August, 2007

Advisory Committee:

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EVALUATING FACTORS CONTRIBUTING TO ENGINEERING TECHNOLOGY STUDENTS' INTRODUCTORY PHYSICS EXPERIENCE

By Daniel A. Reed

Thesis Advisor: Dr. Michael Wittmann

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Teaching
August, 2007

The UMaine's introductory algebra-based physics course PHY 107 is dedicated to students from the School of Engineering Technology (SET). These SET students come from a wide range of backgrounds and are studying a hybrid of curricula for an engineer and a technician with a leaning toward engineering. In order to appropriately serve this population we must attempt to understand who these students are.

One of the legends surrounding this group is that their struggles with physics stem from having a lower level of mathematics ability than the typical introductory physics student. Through the use of a math diagnostic, the Force and Motion Conceptual Evaluation (FMCE), an updated version of the Maryland Physics Expectations (MPEX2) survey, and a myriad of student, instructor, and SET Coordinator interviews, I sought to develop a data supported view of the PHY 107 students. In this process, I address current course objectives; the extent students develop toward those objectives; and find which factors correlate with physics conceptual development.

I found that despite SET's professional concerns, they care most about developing their students' abilities to make sense of physical and verbal representations of a situation and translate that understanding into meaningful mathematical models. The measure of conceptual development $\langle g \rangle$ tells the extent to which PHY 107 has developed these skills necessary to build

a mathematical model. PHY 107 students only improved ≈12% of their potential for conceptual development as measured by the FMCE.

Mathematic skill failed to contribute to the PHY 107 students' conceptual gain <*g*>, though they do represent the bottom quartile of a typical algebra-based introductory physics course. Of all factors considered in this study, pre- and post-instruction favorable attitudes as measured by MPEX2 coherence and concept cluster scores best-predicted student conceptual development.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank the PHY 107 Lecturer, who has been kind enough to give me precious class-time to collect data and patience for me as I have (re-)learned physics to TA in the course. In addition to the lecturer of PHY 107, the coordinators and director of the School of Engineering Technology have been gracious with both their time and information, offering to share as much as possible to help with my investigation of their students.

Second, I must note my advisor Michael Wittmann. He has provided me the opportunity to create this project without limiting my thoughts until I asked for his help paring things down. In addition to providing me with helpful ideas while creating this project, his friendship and support as I began my venture as a new father and husband has been most welcomed.

The PHY 107 students' humoring my request to run them through a battery of surveys form the core of this study and has made this thesis possible. At the same time, those interviewed, have helped a great deal to shape the character of these students and the PHY 107, which lays the back drop for our discussion.

Although not directly related to this project, Susan McKay has been an incredible personal and financial support throughout my time in the MST Program. Never did I pass Susan without her taking a moment to ask about Julia, my thesis, Natalie's rotations, or some other aspect of importance to me. Her thoughtfulness and concern has helped to make this program a comfortable environment for working. In conjunction with her personal concern she has somehow found funding for me without fail throughout my time here, which includes this summer that I may complete this thesis: Thank you, Susan.

The final people playing significant roles in this research project are John Thompson, Eric Pandiscio, and William Halteman. John and Eric have been kind enough to prod me to search for a smaller, more manageable line of questioning in order to form a thesis. Meanwhile, Bill has offered me his time as I attempted to relearn statistics. The common theme with these three is that they have offered me their time, when they could have been elsewhere enjoying their vacation. I appreciate it.

The two people responsible for keeping me moderately sane throughout this endeavor are my wife Natalie and daughter Julia. Without their constant reminders of the things of greater importance, I would have worked too much, too long, and never have pleased myself. They supply the reason and need for this sometimes-perfectionist to say “good enough.”

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Chapter 1: Introduction

1.1. School of Engineering Technology Students

The PHY 107 students all come from the School of Engineering Technology (SET), which is part of the UMaine College of Engineering. SET is roughly half the size of rest of the UMaine College of Engineering, currently working with 371 students. Sixty-one of these students finished their first year in Spring, 2007 (UMaine Office of Student Records, 2007).

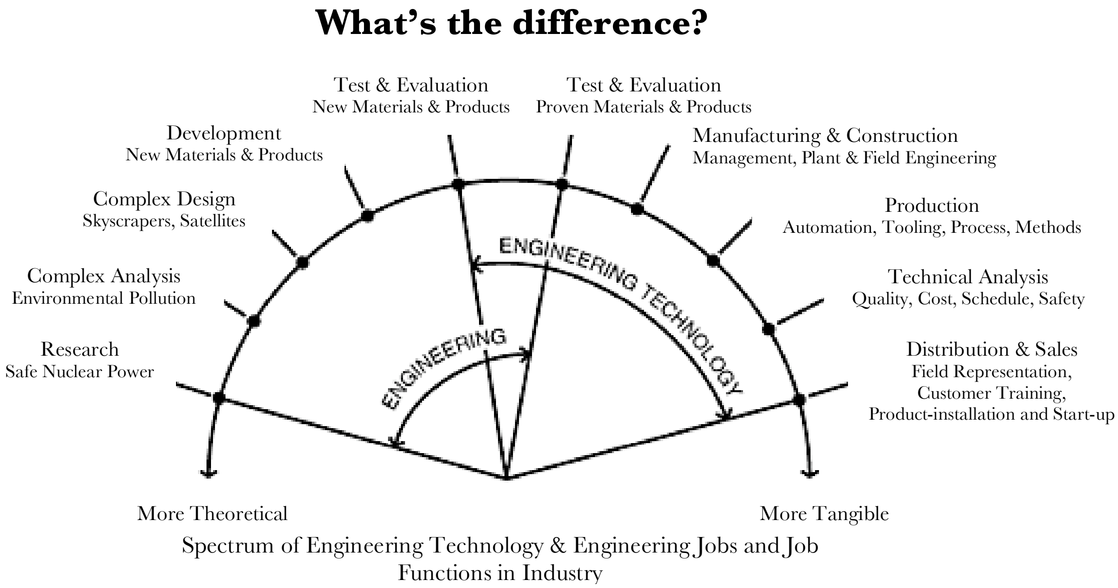

Figure 1: An Engineering Student vs. an Engineering Technology Student (http://www.umaine.edu/set/Whatis/index.htm)

The major difference between these engineering populations is the (non) academic nature of the SET students and concrete nature of their careers (see Figure 1). SET students come to their program through one of two paths; they either choose the more "hands-on" merging of a technical program with an engineering program or they fail to meet the academic requirements of the typical engineering programs. SAT scores and class rank comprise the academic requirements setting the threshold for entry into the typical engineering program. The PHY 107 population is unique in that they represent a portion of students atypical for a rigorous academic program.

As a crossbreed of a 4-year engineering program and 2-year associate's program, the four majors offered by SET accommodate the practical/concrete nature of this hybrid. The majors of SET are as follows: instead of civil engineering, SET offers construction management technology (CMT); in place of electrical engineering, SET students work toward becoming electrical engineering technologists (EET); more concrete mechanical engineers become mechanical engineering technologists (MET) in SET; for the fourth major, in place of the chemical engineers, the SET has developed a surveying engineering technology (SET) program. Together these majors represent an alternate path to becoming a professional engineer or surveyor and provide Maine's small and large companies alike with practical middle management. In the smaller companies, an SET graduate should be comfortable and capable of wearing a variety of hats. Meanwhile, in a larger company, the SET graduate will understand enough from both the white-collar and blue-collar sides to communicate with both sides effectively.

Although the differing goals for the typical engineers and the "hands-on" engineering technologist provide great value to Maine's economy, these academic and career differences may have a dramatic impact in how we can and should approach these students in their course work, particularly when they first arrive to the university. PHY 107 is an introductory course devoted to this entering engineering technology population.

1.2. The Setting

This study will look at the effectiveness of the first semester of the UMaine's algebra-based, Introductory Technical Physics course PHY 107. The PHY 107 course typically welcomes 80-100 students to begin every fall semester. This population consists primarily of first-year male students, a sprinkling of upperclass students, and a few female students. For purposes of this study, only the 62 students participating for all surveys are included.

The course format includes two 50-minute lectures, two 50-minute recitations (called "workshops" within the course), and one 110-minute lab each week. Some attempts have been made to introduce curriculum and pedagogical reform based up physics education research, while maintaining a traditional lecture-based structure. As an example of the research-based reform, the lecture includes some Interactive Lecture Demonstrations (ILD; Sokoloff & Thornton, 2006) These ILDs include instructor-posed conceptual questions meant to involve and engage students through peer interaction (Mazur, 1997), and low-tech hand raising in response to the instructor. In addition to modifications in lecture, the recitations have been transformed from Teaching Assistants (TAs) giving problem solutions in favor of "tutorial worksheets" which require students to work cooperatively in small groups and attempt to reason through the "Why?"s behind the topics introduced in the course (McDermott et al., 2002; Ambrose, 2002). The labs in PHY 107 remain the only unaltered element.

1.3. Problem Statement

As suggested by the non-academic past of the SET population, students currently struggle with PHY 107. Having been a teaching assistant (TA) for this population myself, I have noted two elements within this population, which may contribute to their struggles: poor math skills and attitudes unhelpful to *learning*.

The first element of concern is the students' math background. They are required to take TME 151, a pre-calculus course, as a co-requisite to PHY 107. To enter TME 151, SET requires that they pass the UMaine's online Math Placement Exam (level 2), an exam appropriate for suggesting that a student may be ready for pre-calculus, but should not to be confused with actually knowing pre-calculus material. In addition, SET has some established guidelines for admission into SET. Students must have taken at least Algebra I & II, a semester of trigonometry, *and* have a 520 on the math portion of the SAT. (They must also have taken a physics course in high school.) Despite these measures that SET has implemented, students still appear to struggle with the mathematics required of them in the PHY 107 setting.

The second disconcerting element is the students' attitudes. As a TA for PHY 107, I had plenty of opportunity to experience the students' frustration. As recommended by McDermott et al. in the *Tutorial in Introductory Physics: Instructor's Guide*, "Students are expected to construct answers for themselves through discussions with their classmates and with tutorial instructors. The tutorial instructors do not lecture but ask questions designed to help students find their own answers" (McDermott et al., 2002). This Socratic approach tends to frustrate the SET students very quickly, and as a result they will often refuse to even try to think for themselves. As a TA, I continually battled SET students' relentless pursuit for *the* answer to come from the "authority" in the room.

1.4. Research Questions

Due to the apparent atypical nature of the SET population and the manner in which many of them appear to struggle in Introductory Physics, I proposed the following research questions:

1.4.1. Physics Instructors

- How do the PHY 107 instructors perceive the academic behaviors of their student population?
- What expectations do they have for student development in an introductory physics course?

1.4.2. SET Program Director & Coordinators

- How do the School of Engineering Technology (SET) Coordinators and Program Director perceive the academic behaviors of their student population?
- What expectations do they have for student development in an introductory physics course?

1.4.3. PHY 107 Students

- How do SET students skill sets and indicators compare with more typical introductory physics population?
- How do PHY 107 students believe they should be learning in an introductory physics course?
- Are the current instructional methods effective for conceptual and attitudinal development?

Chapter 2: Methods for Studying PHY 107

As is typical in physics education research, a variety of methods are used to study student attitudes and knowledge. These are described in detail in this chapter, and include individual interviews, previously designed surveys and diagnostic tools, and free response questions. After describing these tools in some detail, I describe the populations that are studied including: PHY 107 instructors, students, and SET instructors. Data from these populations, taken using the described tools, are given in the next chapter.

2.1. Tools of Inquiry

2.1.1. Interviews

One mode of gathering information about students is an individual interview. Due to the nature of my trend seeking, open-ended research questions, I required a format that would allow me to address each subject in a manner offering them the most opportunity to share their perspective. Although the interview imposes a somewhat contrived context for interaction, interviewing offered the best context for ensuring the fewest limits to the information that could be gathered.

Essentially each interview followed a relatively standard format. I would introduce myself and have them read an informed consent form (see Appendix A). Then, after I had obtained permission to audiotape, we would have a little small talk to start things on the light side and distract their attention from the tape recorder. From there the interview roughly followed its respective protocol (see Appendices B, C & D), and strayed from time to time for clarity or interesting tangents. During these conversations, I attempted to work within the subject's comfort zone before asking them to stretch very far. A typical interview lasted about an hour, with some coming to an appropriate end before an hour, while others extended for as long as the interviewee cared.

After conducting all of the interviews, I proceeded to listen to the interviews and take detailed notes of the discussions. I opted for detailed notes over direct transcription, unless someone had a particularly profound statement, because I sought general, large-scale connections between/among groups, rather than subtleties. Students were the exception here because their thoughts, thought processes, and attitudes are really the root of understanding the SET population.

2.1.2. Surveys

To evaluate this relatively large population of students in a manageable fashion, I elected to use previously validated multiple-choice instruments. Using these previously developed instruments has several benefits. First, their creators have already validated them and include distracters taken from students' extended-response answers. Second, I could deliver the instruments in bulk in a relatively small amount time, thereby sacrificing less class time. Third, obtaining data from these surveys takes a small amount of time and already has a history of data available for comparison.

The surveys I used to evaluate PHY 107 students' physics conceptual development and expectations/attitudes are the Force and Motion Conceptual Evaluation (Thornton & Sokoloff, 1998) and the Maryland Physics Expectations Survey 2 (UMPERG, 2002), respectively. In addition to these widely used and established surveys, I also used a pre-published version of H. Thomas Hudson's Mathematical Diagnostic Test to evaluate PHY 107 students' initial math skills when entering the physics course (Hudson, 1986). Only students taking every survey are used for this study, reducing my study population from 85 to 62 PHY 107 students.

2.1.2.1. Force and Motion Conceptual Evaluation (FMCE)

To measure physics conceptual understanding and conceptual development for this study, I used the Force and Motion Conceptual Evaluation (FMCE), developed by Ronald Thornton and David Sokoloff (see Appendix E). Although the Force Concept Inventory (FCI) has a longer history, and therefore, a greater database for comparison, I selected the FMCE due to its ability to address some of the more fundamental elements behind forces (i.e. kinematics) and tease out particular concept clusters. With these concept clusters, you can not only tell whether students have a full Newtonian model, but whether they have a consistent alternative model, or whether they consider different situations differently. Using this notion that students can fail to have a consistent way of viewing fundamentally similar situations, we can see progress toward more correct answers, without actually having the consistent expert answer (Dykstra, 2002).

The value of the FMCE, over the FCI, lies in the ability to look at sub-elements of the test when looking at individual student responses. The FMCE creators claim, "the FMCE is most useful when correlations among student answers on different questions are examined" (Thornton & Sokoloff, 1998). Thus, the FMCE allows us to look at individual students ideas with improved resolution. In contrast, the FCI creators and Heller & Huffman warn against parsing the FCI into parts for analysis, and suggest that the test should only be looked at as a single entity (Hestenes & Halloun, 1995; Heller & Huffman, 1995). I chose to proceed with the FMCE in order to grant the ability see the concepts of the students and class as a whole with greater clarity.

The FMCE, a 47-question survey in a multiple-choice format, requires students to interpret both words and graphs, while offering students a diagram depicting each situation (see Appendix E). The five clusters represented in Michael Wittmann's FMCE analysis template are: Wittmann (2001) designed a template that scores the overall exam and each of five concept clusters: *velocity*, *acceleration*, *Newton's 1st & 2nd laws*, *Newton's 3rd law*, and *energy*. See Appendix F to view the question numbers corresponding to each cluster.

To obtain an overall score, the template utilizes 33 of the 47 questions, excluding: the four energy questions, several questions intended to shift students thinking toward the next topic being probed (e.g. acceleration, N2, N3, etc.), and some questions commonly answered correctly for incorrect reasons (Wittmann, 2002).

2.1.2.2. Maryland Physics Expectations Survey 2 (MPEX2)

To measure attitudes/expectations for this study, I used a revised version of the Maryland Physics Expectations Survey (MPEX) originally developed by Redish et al. (1998). The newer version carries all of the original intent, with a rewording and reordering of questions plus some additional questions probing student epistemology (i.e. beliefs about knowledge and ways of knowing). This instrument poses thirty-one statements and asks the respondent to give a reaction to each statement using a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5) (see Appendix G).

The goal of this survey is to evaluate how students expect to learn physics effectively within a physics course. For each statement a student can either respond favorably, unfavorably, or neutrally. Favorability has been validated by a group of "experts". "[The creators] defined as 'expert' the response that was given by a majority of experienced physics instructors who have a high concern for educational issues and a high sensitivity to students." MPEX creators thought that when a supposed group of experts were surveyed using the MPEX and asked to answer as they hoped students would, each response would have the majority of experts in agreement. As such, they selected five groups to validate their assumption. The five groups consisted of: engineering students from U. of Maryland's calculus-based physics class; members of the US International Physics Olympics Team, high school teachers attending a two-week summer seminar on reformed-based physics education; university and college teachers attending a two-week seminar similar to the high school teachers'; and college faculty that were part of a project to implement Workshop Physics[1] at their home institutions. These groups have been listed in the order the MPEX creators believed they best matched what they would call "experts." Their predicted experts came through with a majority answering in a certain manner on all questions,

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[1] Workshop Physics is a highly-interactive, lab-based course curriculum developed at Dickinson College. The high school & university/college seminars both took place at Dickinson College and were on topics that are part of the Workshop Physics curriculum.

and with greater than 80% agreement on all but three of the questions. On the three questions still having 50-80% of the experts answering the same (agreeing or disagreeing), while one-quarter to one-third of the experts responded neutrally to those statements. Using the majority answer from the group implementing Workshop Physics as our measure of favorable, the five groups were ranked and they answered favorably/unfavorably in the predicted relative order.

Table 1: Ratio of Favorable vs. Unfavorable of MPEX Calibration Groups Relative to Experts (Redish et al., 1998)

	Workshop Physics Sites/ Implementers	College Faculty	High School Teachers	H.S. Olympics Students	Engineering Students
Favorable/Unfavorable	86/7	80/10	73/15	68/18	54/23

The calibration demonstrates the level of expectation a group has that students should (or do) approach learning physics from a constructivist' perspective. Considering the constructivist nature of the pedagogical methods that physics education research has demonstrated to be effective, it may be important for us to understand the extent to which students buy into the constructivist's agenda (Redish et al., 1998).

Though, as seen in Table 1,we can look solely at the general picture, one of benefits of the MPEX2 is its diagnostic capability. Unfortunately the creators recommend avoiding the survey as a *sole* measure to diagnose *individual* students, and instead suggest its usefulness for viewing an entire course. The reason for avoiding using the survey to reveal the detailed picture of a single student may be best viewed through Redish's interpretation of David Hammer's dissertation work:

> …be careful not to assume a student exists in one extreme state or another. A student's attitude may be modified by an additional attitude… or even exist simultaneously in both extremes, depending on the situation that triggers the response. (Redish et al., 1998)

Essentially, a student may apply both favorable and unfavorable attitudes/expectations simultaneously to different questions probing the same idea, or fail to see an attitude that they possess as useful in the introductory physics course. This reasoning sounds very much like the reasoning *for* having multiple questions in clusters. The clusters allow the investigator to see the likelihood of a student to activate appropriate resources across varying, yet similar, situations. These results are based on over 100 hours of interviews to validate the survey (Saul, 1998). To remain consistent with these previous research results, I will utilize interview information to further support any individual or small group claims from MPEX2 data.

Table 2: Overarching Attitude/Expectation Clusters[2]

	Coherence	Concepts	Independence
Favorable	Believes physics needs to be considered as a connected, consistent framework.	Stresses understanding of the underlying ideas and concepts.	Takes responsibility for constructing own understanding.
Unfavorable	Believes physics can be treated as unrelated facts or "pieces."	Focuses on memorizing and using formulas	Takes what is given by authorities (teacher, text, etc.) without evaluation.
MPEX2 Items	3, 4, 6, 8, 10, 13, 15, 19, 21, 23, 27, 28	5, 9, 16, 18, 19, 23, 24, 28, 30	2, 7, 11, 12, 14, 17, 20, 22, 25, 29, 31, 32

The MPEX2 probes three primary clusters and 4 sub-clusters in detail (See Table 2 & Table 3). These attitude/expectation categories include *coherence*, *concepts*, *independence*, *reality link*, *math link*, *personal metacognition*, and *epistemology*. The coherence cluster houses the *reality link* and *math link* as well as some other questions, while independence contains the two remaining subcategories: *personal metacognition* and *epistemology*.

An example of a statement probing coherence (reality sub-cluster) is statement 21: "Although physical laws may apply to certain simple situations like we see in class and lab, they have little relation to what I experience in the real world." A favorable answer disagrees with this statement 21, implying that physics laws connect both within the class and "real" experiences (as indicated by the favorable descriptions in Table 2 & Table 3). Meanwhile, the concept questions focus on the importance of understanding a physical situation to problem solve rather than

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[2] (Saul & Redish, 1998)

manipulating facts and formulas, while disregarding meaning. Statement 16 represents the concept cluster fairly well: "The most crucial thing in solving a physics problem is finding the right equation to use." As implied by Table 2, a favorable answer disagrees with statement 16.

Table 3:Embedded Attitude/Expectation Clusters

	Coherence		Independence[3]	
	Math Link	Reality Link	Epistemology	Personal Metacognition
Favorable	Considers mathematics as a convenient way of representing physical phenomena.	Believes ideas learned in physics are relevant and useful in a wide variety of real contexts	Believes in the importance of resolving things for one's self as opposed to expecting the authority's edict to resolve everything without reflection	Believes that one's own awareness of physics can guide them through unknown territories or at least show them their current limit
Unfavorable	Views physical phenomena and corresponding math expressions as independent with little relationship between them.	Believes ideas learned in physics has little relation to experiences outside the classroom	Expects an authority to resolve any inconsistencies, only needs to remember what came out of the authority's black box	Believes that only an external source can explain physics and the appropriateness of an answer
MPEX2 Items	3, 10, 28	4, 8, 15, 21	2,11, 12, 15, 20, 22, 25, 29, 31, 32	7, 14, 17

The final overarching category of MPEX2 is the independence cluster. This cluster teases out the extent to which students believe they need to or should play an active role in making sense of physics. Statement 22 gives us a fair picture of the independence, epistemology sub-cluster: "Group work in physics is beneficial only if at least one person in the group already understands and knows what they are talking about." Again, a favorable answer disagrees with statement 22, due to its expectation of an authority to tell them what to believe. Though it is favorable to disagree with all of these examples, in order to prevent students from predicting how to answer questions, the MPEX2 has favorable responses requiring both agreement and disagreement. For a

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[3] Meaning of Independence sub-clusters inferred from the clustering on Andy Elby's MPEX2 scoring template (Elby, 2003, personal communication)

more thorough look at the MPEX2 statements and clusters see Appendix G for the survey and Appendix F for a cluster legend.

Redish et al. (1998) refer to the agenda to get students to learn beyond the content and actually practice and develop scientific ways of thinking and constructing knowledge as part of the "hidden curriculum." As stated above, one of the benefits of the MPEX2 and its clusters is that the measure gives instructors an idea of the extent to which students buy into to a constructivist agenda within a physics course.

2.1.2.3. H. Thomas Hudson's Mathematical Diagnostic Test

The role of mathematics understanding by PHY 107 students is a major element of this study. When interviewing the PHY 107 instructors (see section 4.2 for further detail), the instructors highlighted several mathematical areas crucial to student work in PHY 107 where students appear to struggle. These areas of mathematical concern were students' ability to:

- remember and apply trigonometry appropriately
- isolate a single variable to solve an equation
- work with fractions appropriately/reason across the equal sign
- solve multiple equations with multiple unknowns
- recognize symbols and use them in place of numbers

Previous work by David Meltzer on the correlation between students' math ability and correlating with (electrical) conceptual gains made use of a pre-existing diagnostic instrument (Meltzer, 2002). He provided a copy of this diagnostic: the H. Thomas Hudson's Mathematical Diagnostic Test (Hudson, 1986; see Appendix H). The diagnostic contains 38 multiple-choice questions. Unfortunately, the diagnostic came with neither a solution key nor any clustering information. Thus, I proceeded to organized the questions and cluster them according to category. In all, I developed seven clusters:

- Isolating variables
- Solving simultaneous equations
- Graphing
- Fraction addition
- Working with trigonometry
- Performing calculations with scientific notation
- Using letters as constants

One important note here is that although some skills overlap categories, for instance, people often solve simultaneous equations by isolating variables, I have chosen to only place questions in a single cluster. This approach distinguishes the compounding skill necessary from the primary skill and places the multiple-category question in the more compounded category (e.g. simultaneous equations instead of isolating variables). To view which questions correspond with which cluster refer to Appendix F.

Among the seven clusters, five align well with areas PHY 107 instructors expressed concern. These five clusters are*: isolating variables*, *doing simultaneous equations*, *working with trigonometry*, *fraction addition (division by parts)*, and *using letters as constants*. The clusters allow us to discuss whether students struggle with particular skills, and also whether these particular skills correlate with conceptual development.

2.1.3. Free-response

An initial goal of this investigation was to discern whether the math-trouble observed by the instructors was due to students possessing a low-level math skill set or whether the physics context interfered with access to their mathematics skills. A free-response question would allow us to see more than just whether the students could answer a question entirely correctly; free-responses allow us to see both the extent of correctness and possible pitfall trends for this student population. As explained below, free-response questions were not used for diagnostic purposes in this study.

2.2. PHY 107 Instructors

To address the questions related to PHY 107 instructors in this study:

- How do the PHY 107 instructors perceive the academic behaviors of their student population?
- What expectations do they have for student development in an introductory physics course?

I interviewed the instructors and had them take the MPEX2.

2.2.1. MPEX2

In order to allow comparisons the PHY 107 instructors answered the questions as they hoped their students would, much like the MPEX creators did to define their “expert” for comparison purposes (Redish et al., 1998). The addition of the MPEX2 serves as a means to directly compare the PHY 107 instructors’ hopes for student expectations/attitudes toward the physics course with those of the SET Coordinators and the students themselves.

2.2.2. Interviews

I chose to interview the lecturer responsible for PHY 107 as well as several current and previous teaching assistants (TAs). The lecturer is an obvious choice because the lecturer forms the overall structure of the course, the curriculum, and curricular materials based upon his perceptions of the SET population and his expectations. The reason for including the TAs stems from the notion that though the TAs play little if any role in creating the course structure, they implement the chosen curriculum and account for two-thirds of the students’ instructional time. Since TAs interact more directly with the students, lead the portions of the course where students participate more actively, and account for much of the student-instructor feedback (grading), they should have valuable insights. These insights should delve deeply into both how these students interact with the PHY 107 course and how they, as instructors, attempt to develop these students through the course.

The differences between what the lecturer and TAs can offer us for information is reflected in their protocols (see Appendix C). Though I question both the lecturer and TAs about the strengths and weaknesses of the students, I expected and received slightly different responses with regard to scale. When it came to labs and workshops I questioned the lecturer about the reasoning behind the lab and tutorial choices and modification. The TAs, on the other hand, served as a lens to see the actual implementation of labs and tutorials, and individual instructor strategies for working with the PHY 107 population. Last, I wanted to compare the agendas of the workers (here the TAs) and the administration (the lecturer), essentially asking, "What would we like the PHY 107 students to retain from the PHY 107 course?"

2.3. PHY 107 Students

In order to address the student-related questions of this study:

- How do SET students skill sets and indicators compare with more typical introductory physics population?
- How do PHY 107 students believe they should be learning in an introductory physics course?
- Are the current instructional methods effective for conceptual and attitudinal development?

I used both quantitative and qualitative measures. The specific measures are discussed in detail below.

2.3.1. Mathematical Skill

2.3.1.1. The UMaine Math Placement Exam

Two purposes existed for this study evaluating the PHY 107 students' mathematical skill. First, the PHY 107 instructors felt that the students come to PHY 107 underprepared mathematically, and therefore, struggle with physics. So, we want to know whether the PHY 107 students do indeed come with a lower than typical mathematic skill set than we should expect from an algebra-based physics population. Second, we would like to know whether the math skills these students enter with have any impact on physics conceptual gains as measured by the FMCE.

Part 2 of the three-part UMaine math placement exam is currently used by SET to determine readiness for TME 151, SET's pre-calculus course and co-requisite for PHY 107. SET students must qualify as ready for TME 151 to take that pre-calculus course, and thus PHY 107.

Several issues were of concern with regards to the math exam.

1. What material does Level 2 of the Math Placement Exam cover?
2. What are the conditions for taking the exam?
3. Is the exam a diagnostic?
4. How does the math placement exam determine a student's readiness?
5. Is the data readily available?

To answer these questions, I met and interviewed the creator of the UMaine math placement exam.

During the interview, the creator informed me that the exam was online and that, at that time, I could view the exam (any of the 3 parts) solely by having a valid student ID number. Once I opened the online exam, I could print out the exam and close it out if I wished in order to come back and actually fill in my answers on the computer later. Or I could continue, having 60 minutes to answer the 20 multiple-choice questions (see Appendix I to view part 2 of the math placement exam). In addition, a student can take the exam as many times as desired, with only the highest score remaining in the exam database for instructors/advisors to reference. Although students are never told which questions they have correct, at the end of every test attempt, they are told the number of questions correct.

One rather discouraging element about this format is that students can have whatever resources they wish, whether textbook, calculator, friend, or parent; however, the exam does come with a warning. The warning comes before they select which part of the test to begin with and informs students that scoring higher than their actual skill level may have severe consequences of struggle and throwing money away: “Dollars are too precious to waste on a course you are bound to fail.” After this warning, students are then asked explicitly to tuck away their calculator because again, “you will gain no advantage by using calculator, and in fact, may find yourself in a course that [is] too advanced for you.” (https://www.umaine.edu/mathtest/taketest.asp) Despite these warnings, some students, like those entering SET, need to begin on a certain track or accept the idea of a five year bachelor’s program. Thus the risk for borderline SET students may be worth the potential consequences and certainly shed doubt on the validity of the math placement scores for the SET students.

From the interview with the placement test creator, two other items of importance were revealed. One, the exam had not been created to be a diagnostic, or tool to discern where a student may be lacking. Instead, it represents a general algebra skill indicator; in order to give students an idea types of skills expected of them for certain course levels. The exam also gives advisors a basis as to whether a given student may be ready for a particular course. Here readiness means that the student has a chance of getting a C- or better. Ten out of twenty correct tells a student that she may be ready for a given course.

In order to obtain student data from the math placement exam, I entered the web page for the math placement test. By using student ID numbers, I could access each score one at a time. Although the data is nothing more than the number correct out of twenty, I still wanted to obtain student data for comparison with a math skills exam that tested the skills the PHY 107 deemed both critical to the course and problematic for the PHY 107 students. PHY 107 instructors claim that their students struggle with; isolating variables, solving simultaneous equations, and working with fractions, trigonometry, and symbols (using letters in place of numbers). Of these categories, part 2 of the placement exam lacks trigonometry and use of symbols as constants. I obtained math placement data for 51 of the 62 people in this study in order to compare those scores with a more appropriate instrument for measuring those skills of concern to PHY 107 instructors.

2.3.1.2. Math Diagnostic

After organizing Hudson's math diagnostic into clusters and finding all of these clusters appropriate to this study, I was ready to implement the exam with the incoming PHY 107 students. Refer to Appendix F to view questions corresponding to each cluster.

I administered the math diagnostic in its entire 38 multiple-question format (as seen in Appendix H) during the first lab period of the semester, after a lecture-and-a-half of physics instruction. The lab began with me introducing myself. I informed the students that this diagnostic served two purposes. One, it would give them an idea of what kind of math would be expected of them and give them an indication of some areas they might want to brush up on. Second, it would help us to better understand them, the SET population, and better adjust the course to meet the SET needs. The announcement continued with me asking students to:

- Show all their work on the given sheets, clearly indicating any spill over work with the appropriate problem number
- Put away their calculators in order to help us better understand what they know or can figure out on their own
- Leave items blank if they felt inclined to guess, as a guess wouldn't help anyone, them or me

- Make a note and clearly indicate their answer, if they got to a point and swore that they had a correct answer, but the answer was not one of the options given.

Even though I made an appearance and gave my five-plus minute introduction, the TAs for their respective section stayed to proctor the tests. From talking with the TAs and being one myself, the majority of students were done within forty-five minutes to an hour and fifteen minutes. For each lab section, we did have a handful that used the entire hour and forty-five minutes allotted to them.

2.3.2. FMCE

To measure students' conceptual understanding of physics and their conceptual growth over the course of a single semester of introductory mechanics, I administered the FMCE (see Appendix E). This process began with all students taking the FMCE during the first workshop (recitation) of the semester (prior to any instruction), serving as their pre-instruction evaluation. After handing each TA materials for his workshop and explaining the process and purpose, I had the TAs proctor their students for their respective workshops and collect the FMCE survey with the answer sheets. Most students finished this survey within half an hour, although a handful did require the full 50-minute time allotted.

For the pre-test, I failed to obtain appropriate scantron sheets. Thus, I provided students with answer sheets, which I then typed into a standardized Excel FMCE scoring template (Wittmann, 2001).

The post-test of the FMCE came during the final 2-hour lab of the semester, directly following the MPEX2, and preceding course evaluations, which both took place in the same time period. Once again, the TAs proctored the survey.

Several elements surrounding this round of surveying differed in a notable way. First, the students were prompted to attend lab and take the surveys seriously. Although no penalty could be given for little effort on the students' part, 10 points were added to their total semester test points (not to be confused with average) for participating. Second, students seemed antsy and knew that they had three surveys to respond to before they were done. Last, although only a minor difference, the students filled in ten-choice scantron sheets instead of writing their letter choice. I then, processed the scantron sheets and entered the data into the FMCE scoring template. All 62 people in this study have matched pre-/post- FMCE data.

2.3.3. MPEX2

The MPEX2 had a pre-/post-test format similar to the FMCE. The pre-test took place during the first 30 minutes of the very first lecture. The MPEX creators note that students have a tendency to answer more in a manner as they perceive an expert would rather than how they actually believe (Redish et al., 1998). Therefore, the course lecturer remained out of the lecture hall to avoid the possibility of stereotype-biases from creeping in to the picture. Meanwhile, I introduced myself as someone from the MST program and briefly explained that I was conducting a study within the PHY 107 class. At the same time, each student received an informed consent form similar to the one in Appendix A. Students then completed the MPEX2, writing within the survey questions for free response items and filling in the five-choice scantron sheets for their Likert-scale selections. I proceeded to have the scantron sheets processed and then placed the data in the MPEX2 excel scoring template created by Andrew Elby, one of the MPEX2 creators (Elby, personal communication, 2003).

The MPEX2 post-test began the final lab period of the semester. During the same period they also took the FMCE and course evaluations. As mentioned above, the lab TAs proctored this battery of testing and the students were prompted to attend with an offering of a small boost to their total test points for the semester. At the conclusion of surveying, these scantron sheets were processed and the data entered into the MPEX2 scoring template. All 62 people in this study have matched pre-/post-MPEX2 data.

2.3.4. SAT

SAT scores serve as another measure for characterizing students taking PHY 107. For instance, verbal ability may play a role in students' ability to successfully share what they know on a text-based conceptual survey. Another element of interest is how well the SAT accounts for the skills associated with the math diagnostic. Because students already need to take SATs as part of their application process, future work with these students could forego additional testing and merely obtain the data from UMaine's Office of Institutional Studies if this study finds strong correlation.

To obtain SAT information I needed to have students sign an informed consent, approving my obtaining their SAT scores. This informed consent form resembled the one found in Appendix A, but this consent form told them that I would access their SAT scores, which they had to initial by the text statement, and sign at the bottom. While I gave my extended pre-math diagnostic talk I also handed out these special informed consent forms and asked the students to sign them. As I called attention to the SAT waiver, I verbally assured students that their scores would be used to help me with my research and would in no way affect their course grade. I have SAT scores for 56 of the 62 students in this study.

2.3.5. Math Question in Physics Context

Initially I had hoped to look at transfer of math skills into the physics context. The question asked was whether the PHY 107 students came to the class with insufficient math skills in the areas that concerned course instructors, or they could do the math, but the physics context interfered with applying their math skill. By using the math diagnostic as the math context and creating a problem in which they both needed to understand and interpret a physical situation (see Appendix J), I sought to compare the five math skills: applying trigonometry, isolating a variable, solving simultaneous equations, using letters as constants, and addition of fractions (with division by parts embedded within). To allow time for the students to become more familiar with the physics setting, I waited until the second course exam to investigate the interaction of their math skills and physics understanding.

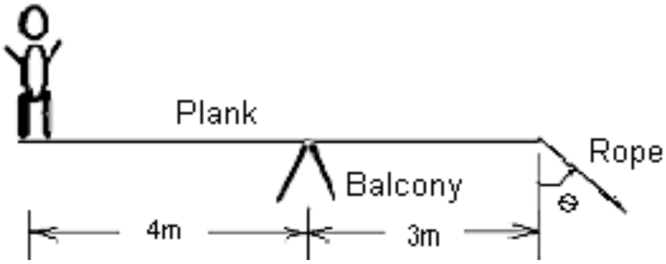

Figure 2: Diagram of physics problem

The physics problem in Appendix J had several key components for attempting to make the situation more accessible to students before asking them to symbolize the situation mathematically. First, I created the story housing this torque question in a context I had assumed the students would find more realistic, and therefore, easier to visualize. Second, a picture of the situation (see Figure 2) coupled with an appropriate free-body diagram was given to the student, freeing them of the burden of discerning the forces involved and the locations where they act. Third, part (a) of the question attempted to get the students to connect forces with the idea of torque, by offering them purely conceptual question, which more or less asks them, “Are you just dealing with forces here, or do distances matter, too?” The last layer of scaffolding we assembled was a change to the board in part c) so that students could continue with part c) independent of whether they got part (b).

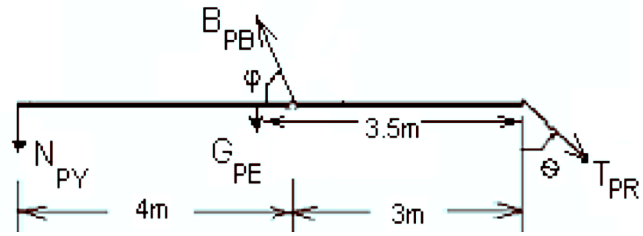

Figure 3: Free body diagram of the plank system

The mathematical elements of interest lie in parts (b) & (c). In part (b), students needed to resolve the Tension in the rope, given θ, the weight of the person, and weight of the plank. Within this process, I looked for four of the five mathematical elements: applying trigonometry, isolating a variable, using letters as constants, and working with division by parts (embedded within addition of fractions questions). Using letters as constants (or symbols in place of numbers) came into play with seeing τ for torque, T for tension, and the tendency to either begin with a generic student-created equation or a numeric equation. Isolating variables arose when establishing the sum of the torques and separating the elements to solve for tension.

$$\sum \tau = 0$$

$$N_{PY}(LA_{N_{PY}}) + G_{PE}(LA_{G_{PE}}) - T_{PR}\cos\theta(LA_{T_{PR}\cos\theta}) + T_{PR}\sin\theta(LA_{T_{PR}\sin\theta}) = 0$$

Equation 1: Summing torques for part (b) about the balcony

Students needed to implement trigonometry to resolve how much of the tensile force acted in the y-direction because only the y-component of the Tension causes a torque about the balcony. Looking at Figure 3 and Equation 1, the tricky part arises from here the students tending to want to say sin goes with the y-direction and cos the x-direction as opposed to considering the meaning of cos and sin. Last, the division by parts came when students needed to divide the entire opposite side of the equals side by cosθ*(lever arm of Tension component), as opposed to a single torque on the opposite side of the equals sign.

Part c) brought in aspects of solving simultaneous equations (i.e. resolving sum of torque and/or sum of force component(s)), with isolating variables embedded in this process; using symbols to represent numbers/ideas; and trigonometry in the way of Pythagorean theorem and sorting out sin and cos for components of the force on the plank by the balcony.

Despite these intentions and precautions, the question elicited very little useful data. One third of the students came up with nothing beyond part (a) or showed no intelligible mathematical work. The middle third did little more. To salvage what I did have I chose to still use this in-context question as means to select students for interviewing.

2.3.6. Interviews

2.3.6.1. Selecting Interview Candidates

Table 4: Organizing students based on relative performance on Math Diagnostic-In-context problem

	L-L	L-M	L-H	M-L	M-M	M-H	H-L	H-M	H-H
N	11	8	7	7	5	6	5	6	9

I began the interview selection by breaking the math diagnostic group into three bins, based upon how they performed on the math diagnostic relative to the rest of the PHY 107 class. As suggested above, I then broke the students into bins based upon their work from the torque problem. The low and high groups were sorted out, while the middle group made up the remaining students. Low students fell into their bin by either leaving the page beyond part (a) blank, or attempting to start something, but failing to show any success with isolating tension or recognizing that they needed trigonometry. Meanwhile, the high students showed no symbol confusion between τ and T, successfully distinguished mass from weight, used trigonometry correctly to find appropriate force component, used lever arms in conjunction with force to find torque, recognized that multiple torque acted in part (b), and found torque about only one location.

Pairing the bins from the math diagnostic with their respective bins on the torque problem placed the data into nine combinations: low-low, low-mid, low-high, mid-low, etc. (see results in Table 4). At this point, I organized the bins so that they had more comparable numbers in each bin for sampling. I began the filtering process by removing the high=high group (9 students) from consideration because I assume they are least likely to elicit the weaknesses or general trends in the population. Also, because the PHY 107 instructors assume math skills are interfering with their students learning physics, the group that understands the physics and has the math skills will tell us nothing with regard to the instructors' concerns. Continuing with an emphasis on lower-skilled math students, I kept all three low-math-skill groups as their own bins ranging from 7-11 people and binned the remaining high-math-skill groups as a single bin of 11 students. The middle-math-skill groups were smaller than all of the other bin sizes (6 students each) and I wanted to refrain from overpopulating my interview sample disproportionately with the middle-math-skill students. The compromise came by binning the mid-low, mid-mid, and mid-high groups together, giving me a single bin roughly double the number of most of the other bins.

With 5 bins in place, I intended to draw a single student from each bin, with the exception of the mid bin, from which I would draw two students. Within each bin, I found the mean and median score of the sample in the bin for the math diagnostic clusters, SAT, pre-FMCE, and pre-MPEX scores and chose the student that appeared to match most closely with these indicators. The exception for selection here was the mid bin, for which I selected individuals more representative of the score of the top and bottom quartile scores. After selecting individuals, whose names I was blind to until after selection, I emailed the students individually and pulled them aside and spoke with them personally to secure an interview. In exchange for their time, I offered them a help session before their final.

Aside from the low-low students, I was able to secure all the students selected in this process. To replace the low-low students, I looked to see what SET areas I had failed to account for. It appeared that I had all of the majors except surveying in the picture. In my search for an appropriate candidate based upon the given criteria, I selected a lower scoring mid-level math student who had also performed in the lower-third on the torque problem and was a surveying major[4]. Overall for interviewees, I had a CMT major for the low-mid bin, a CMT major for the

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[4] Though the UMaine's database had this student as an SVT major, the student indicated CMT as his major on the post-instruction MPEX2. All data regarding this student is presented by his indication of CMT.

low-high bin, a CMT major for the mid bin (mid-high), an EET[5] major for the mid bin (mid-mid), an CMT[4] major for mid bin (mid-low), and an EET major from the high bin (high-mid).

2.3.6.2. Conducting Interviews

At the time I conducted the student interviews, I still needed to organize the scope of all of my data and still required time before discarding the notion of looking more at the alleged math problem being more of a contextual issue. As a result, the first two-thirds of student interviews centered around students redoing the torque problem discussed above (see Appendix J). Some of the interview dialogue and goals, while fascinating, no longer pertain to the research questions, and thus, will be omitted from further discussion. The goals of the final portion of these interviews, which I will discuss, pertain mainly to students' attitudes and approach/interaction with the course and its current structure (see Appendix D, under "Follow up questions"). Although not explicitly part of the interview protocol, I asked all of the students about their study habits and each aspect of the course (i.e. lecture, lab, workshop) and probed their reasoning/beliefs regarding their thoughts on these topics.

2.4. SET Directors, Coordinators, and Instructors

To address the SET-related questions of this study:

- How do SET students skill sets and indicators compare with more typical introductory physics population?
- How do PHY 107 students believe they should be learning in an introductory physics course?

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[5] Though the UMaine's database had this student as an MET major, the student indicated EET as his major on the post-instruction MPEX2 survey. All data regarding this student is presented by his indication of EET.

- Are the current instructional methods effective for conceptual and attitudinal development?

I chose to interview and survey the SET Coordinators and the SET Director.

2.4.1. MPEX2

Like the PHY 107 instructors, I had the SET Coordinators take the MPEX2 and respond to the statements as they would like their students to respond. This survey data gives us a way to directly make comparisons between how SET coordinators expect their students to interact with a physics course and the expectations of PHY 107 instructors or SET students, themselves.

2.4.2. Interviews

2.4.2.1. The Director and Coordinators

The reason for selecting the coordinators and director instead of a random collection of instructors representing each discipline lies with the nature of their positions. Because part of my concern here is to discern the SET agenda for a physics course, I wanted to speak with those responsible for discussing and implementing the big picture plans for SET. Additionally, all SET coordinators are also instructors in their respective discipline, which allows them a personal view of these SET students. Through teaching their classes rarely exceeding 30 students and often having the possibility to interact with their students for more than a single course, they should be able to offer a more accurate description of who their students tendencies: good and bad alike. Working under the assumption that coordinators and the director also play a role in student selection, I thought they could also describe what it is they expect from their students for their respective disciplines. The protocol (see Appendix B) implemented for these interviews reflect these ideas.

2.4.2.2. Math Instructor

Following some initial data analysis on the math diagnostic, I set up an interview with one of the SET math instructors who teaches TME 151, the pre-calculus class co-requisite to PHY 107. I thought these instructors might have insight into where and why the SET students struggle. The format of this interview followed the same trend as the SET coordinator interviews (see Appendix B) beginning with the instructor's perceptions of the SET students. However, with the math instructor my interests lie primarily with their experience working with the SET students mathematically and how they interact with math. To help better understand where the students may have had trouble with the math diagnostic clusters, I had him go through each one of the questions and propose what proportion of the students would answer correct, and additionally, where those students that struggled might get hung up. In this manner, I could use the instructor's experience to help fill in the story of the SET students' perceived mathematical struggles from the math point-of-view.

Chapter 3: Accumulated Data & Analysis

Before we can consider the data below we must first realize who the data represents. Only those who participated on the math diagnostic and all stages of pre-/post- testing for the FMCE and MPEX2 are included for this discussion, as is the common practice (Hake, 1998; Cummings et al., 1999; Meltzer, 2002). Among those fully present for this study, students demonstrating indifference toward the surveys (i.e. filling in the same circle for all responses) were also dismissed from the data set. Now let us consider the results of the math diagnostic, FMCE, MPEX2, and SAT and see how they align with the interviews.

3.1. Math Diagnostic Results

The purpose of the math diagnostic is to inform us of the level of math skills with which the SET students enter PHY 107. To understand the forthcoming data, we must have something for comparison to frame our discussion. Thus, let us look to the aforementioned Meltzer study (Meltzer, 2002) and Iowa State University's algebra-based introductory physics course (no longer taught by Meltzer).

Table 5: David Meltzer's 1998 & 1999 Algebra-based Introductory Physics Courses' Spread on the Math Diagnostic (Meltzer, 2002)

	1998		1999	
	N	Mean Score	N	Mean Score
Top half	28	89%	37	86%
Bottom half	31	63%	36	55%
Top quartile	13	93%	21	90%
Bottom quartile	14	49%	20	44%

As seen in Table 5, the difference between means of the top portions of students relative to the bottom appears rather large. Even more disconcerting are the differences between half and quartile means. The top half mean only differs five percentage points from the top quartile, but for the bottom half we see roughly a 10-point disparity between lower half and lower quartile means, implying that the lower-quarter drastically lowers the lower-half's mean.

The second lens for viewing these scores comes from the same algebra-based physics course now under a different instructor. Iowa State University's algebra-based introductory physics class uses the same diagnostic to help raise student awareness of the level of math skills expected of them and requires students who perform poorly in various areas to complete supplemental assignments from H. Thomas Hudson's *Mathematics Review Workbook for College Physics*. In addition to requiring review, the instructor strongly advises students scoring "low" on the diagnostic to drop the physics course and address their math skills before attempting physics. The instructor illustrates "low" through two data. One, the average score for the diagnostic typically falls around 71% (27 correct out of 38). Two, "in a previous semester, of those students who scored below 20 [53%], less than 7% earned a grade of B- or higher, while 82% received a grade of C- or below, or failed to complete the course." Let us consider Meltzer's data and the warnings of a more recent professor of the same course as we view PHY 107's diagnostic data (Crawley, 2002).

Before looking at the diagnostic clusters applied ad hoc to the previously existing math diagnostic, let us look at how PHY 107 performed on the diagnostic as a whole.

Table 6: PHY 107 Performance on Entire Math Diagnostic

	Overall Mean (s.d.)	Top quartile	Bottom Quartile	Scoring below 52.6%
Score	46.7% ± 19.1%	60.5%	31.6%	68%
N	62	18	16	42

In Table 6 we can see that according to Meltzer's data and Iowa State's interpretation, the majority of PHY 107 students enter PHY 107 with "low"-level mathematical ability (see Appendix H to view the diagnostic test). While the lowest quartile in Meltzer's study was around 45-49%, the mean of the PHY 107 population is in a similar area. Thus, the course mean is lower than the 52.5% threshold under which students had an 82% chance of scoring a C- or lower in

Iowa State's algebra-based course. The data suggest that PHY 107 population will struggle mathematically, even when compared to a typical algebra-based physics population.

Although the overall picture appears grim from the above data, it is possible that the areas of particular interest to the PHY 107 instructor will allow for a more encouraging analysis.

3.1.1. Diagnostic Clusters

To view the question range for each cluster described below, see Appendices F & H.

3.1.1.1. Isolating variables

These three single step problems involved nothing more than isolating the one unknown variable and solving for it. PHY 107 students performed very well with single isolation of variables, having a class mean of 80% and median of 100% (3 out of the 3 questions correct). This series of questions seemed to have a ceiling effect, with students heavily skewed to the high end of the scale (see Figure 4). A median of 100% and a mean of 80% suggest that those performing poorly isolating a single variable, performed very poorly.

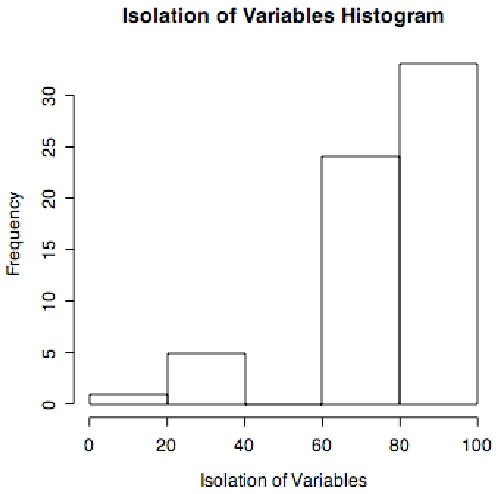

Figure 4: Results from isolating variables

3.1.1.2. Solving Simultaneous Equations

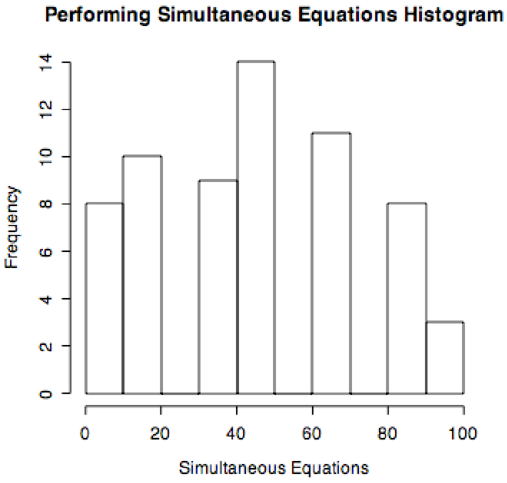

Figure 5: Results from solving simultaneous equations

These six multiple-step problems ranged from solving a system of two equations to creating a relationship from a word problem and then solving the system of equations. The PHY 107 students solved the simultaneous equations, but not well, with a class mean of 46% and median of 50% (3 of 6 questions correct): 50% of the students answered each individual question correctly on 5 of 6 questions, except problem 24. Within the overall simultaneous questions cluster, students had a normal distribution (see Figure 5).

For problem 24, only 11% of the students obtained the correct answer (D), while 32 students (52%) selected (C). For this word problem, students need to translate the word problem and make sense out of rates adding a layer of complexity on top of the straight translation of a word problem to simultaneous equation for problem 12. The rates appear to be the factor creating the problem for these students because 32 students answer as though they could subtract the given combined rate from that of the given individual flow rate in order to find the remaining individual flow rate. The SET math instructor would describe this as the SET students' struggle to unitize properly or select appropriate grain size for working within a given problem.

3.1.1.3. Carrying out Trigonometry

The trigonometry portion asked students eight questions regarding use of the Pythagorean theorem given a triangle, calculating a square root with summing squares beneath the square root, and generally questioning their ease with what trig functions mean. With the trigonometry, students struggled slightly more than when solving simultaneous equations. The class mean resides at 41% and a median of 38% (3 of 8 correct). Students answered most of these questions with 35%-50% accuracy; however, three problems stand out. Problems 8 and 33 had over two-thirds of the population responding correctly; meanwhile, problem 36 stumped just over 90% of the. Like in the simultaneous equations cluster, student responses to the trigonometry cluster were distributed normally (see Figure 6).

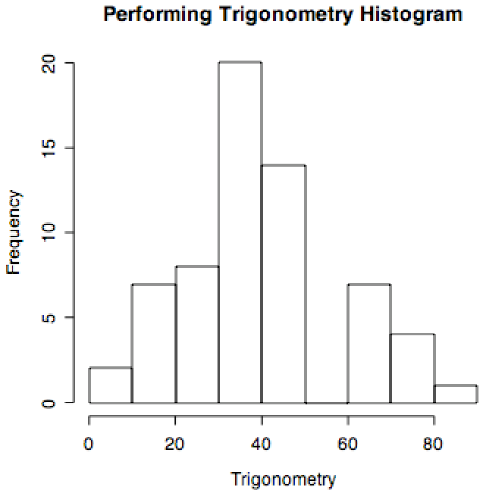

Figure 6: Results for working with trigonometry

3.1.1.4. Fraction Addition (Division by Parts)

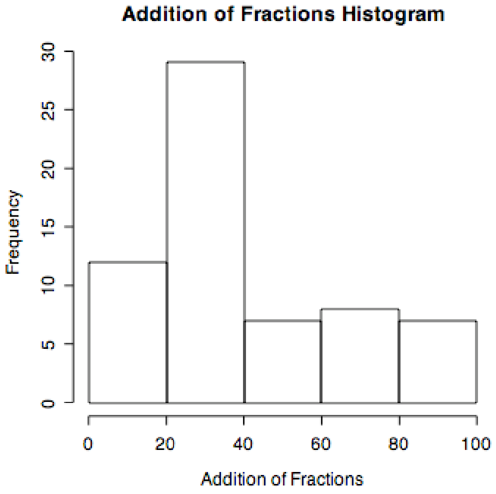

Figure 7: Results for adding fractions

When students find a common denominator, they must realize that if there are any mathematical expressions in the numerator, the denominator applies to each term within that expression and still must respect the order of operations. As PHY 107 instructors noted from observations, PHY 107 students struggle very much with this sort of a process. On the math skills diagnostic the PHY 107 students performed slightly worse on the four fraction addition problems than the trigonometric cluster, scoring a mere 38% for a mean and 25% median. Of the four fraction addition problems, students scored near 50% on numbers 13 and 23; however, problem 35 only had 30% succeeding and #31 was answered correctly by all but 14%. Recall that the questions on the isolation of variables cluster appeared easy for PHY 107 students, creating a ceiling effect. The fraction addition cluster seems to create a floor, measuring very little of the students' abilities (see Figure 7).

3.1.1.5. Using Letters as Constants

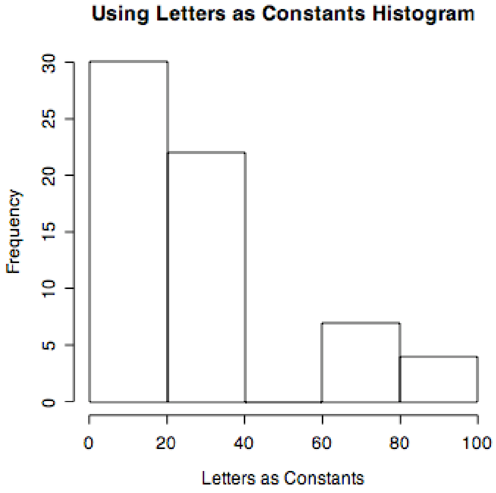

Figure 8: Results for using letters as constants

For this three question cluster, students needed to use letters to represent both constants and variables; similarly physicists use *g*, *G*, *k*, *B*, and other constants within an array of variables. These problems required either a single isolation of a variable or solving simultaneous equations. Unlike the other clusters, no particular problem had a lower success rate caused than others; although students did perform slightly better when performing the single isolation of a variable. The PHY 107 students answered these three questions (16, 17, 18) in the range of 20-30% correct (mean: 25%; median: 33%). The consistently poor performance of PHY 107 for using letters as constants formed another floor effect, revealing very little of the PHY 107 students' capabilities (see Figure 8).

3.1.2. SET Math Instructor's Explanation of Where and Why the Students Struggled

After conducting the math diagnostic, I took the questions to an SET math instructor to evaluate the questions and to tell me how the students would likely do on each cluster question and why[6]. Surprisingly, the instructor predicted the mean of incoming SET students within 5% on each question.

Before actually going into detail with each question from the clusters, the instructor had several general statements regarding items that the SET students struggle within mathematics: "unitization", definitions and terminology, fractions and working with fractions. Here unitization

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[6] At the time I saw the instructor, I had yet to transcribe the PHY 107 interviews. As a result, my discussion with the SET math instructor fails to reflect on the "addition of fractions" cluster.

means the ability to create a system and treat it as a whole rather than a series of parts. The students want to see that every symbol means something rather than having a symbol applying to a whole group (e.g. the distributive property or dividing an entire side by a variable, instead of just a single item). Definitions and terminology refer to students' mastery of the technical mathematical language and fundamental rules (e.g. order of operations apply even as problems become more complicated; meanings of sine, cosine, & tangent; variables need not be defined by a number to work with them).

With regard to technical language, students may be able to perform an operation, but if asked to perform that operation by name, many students may not know what to do. The instructor says that although students' technical vocabulary/comprehension does improve over their series of math courses, that improvement dwarfs their gains in skill development.

Fractions and working with fractions, the last item mentioned, appears to be problematic for many throughout their study of mathematics. "Numerical fractions only throws off a few," but when you start bringing in variables and operations "60-70%" will struggle. Following the instructor's observations on fractions and review of what concerned the PHY 107 instructors, I added the fraction addition cluster to our clusters of concern from the math diagnostic.

With this general list of concerns from the math instructor, we proceeded to discuss the questions from the math diagnostic (for detailed descriptions, see Appendix K). A variety of reasons for struggling arose from this process. One, when a greater number of steps are involved, the SET students may lose themselves along the way. They have a greater chance of having sign or simple mathematical errors. In addition, even if they can perform a simple arithmetic order of operation on its own, when more operations, particularly more advanced operations (i.e. square roots, trig functions, exponential, etc.) come into play, ideas that they might use in another, simpler problem setting often fail to surface. Two, if they have to work with anything beyond numbers the entering SET students will struggle (e.g. solving in terms of…). Three, word problems or "applied problems" create difficulties because students have to come up with the relationships themselves and may fall back to trial-and-error in hopes of stumbling upon an answer. Last, terminology, as mentioned in general terms above, tends to leave the incoming SET students at a loss of what to do.

In light of the SET math instructor's insight, let us now look at what kinds of processes each cluster entails. Isolating variables requires very few steps and allows for uninhibited skill application, suggesting that the SET students should do well, as they did. Solving simultaneous equations involves multiple steps and, if using the substitution method, require students to unitize items or cluster terms as systems. Considering both of these items leave students stumbling, the diagnostic's roughly 50% efficacy seems fitting. During my discussion with the instructor, the instructor noted that roughly two-thirds to three-quarters of the students would have had trigonometry before. With at least one-quarter of the SET population already at a deficit with regard to trigonometry, the additional order-of-operations requirements, and half of the questions using letters instead of numbers, we come to the trigonometry cluster scores slipping slightly relative to the simultaneous equations cluster. Falling still further, we have the addition of fractions cluster entering. The SET math instructor claims that 60-70% have a real aversion to fractions utilizing variables and multiple operations. With the multiple steps required, the greater need to keep order in order of operations, and a requirement to demonstrate some skill of unitizing portions in order to create systems (which act as units), all of which the instructor noted as problematic for the in coming SET students, its no wonder such a high percentage are "scared" by fractions. Within the cluster on the diagnostic, the students saw only one problem that involved numeric manipulation. Thus, the steadily slipping results seem to follow the math instructor's observations. Last, and least, we have the use of letters as constants, which essentially plastered the poor students with jargon, with letters serving differing purposes, and multiple steps, leaving but a few students standing.

3.2. FMCE Results

Though one of the great benefits of using the FMCE is the clustering capability, a search of previous work only yields overall pre/post scores and <*g*> scores. Thus, we will first discuss how PHY 107 students relate to other courses and types of instruction based upon these three indicators.

Overall pre- and post-FMCE scores stem from rubrics provided by the FMCE creators and give an overall FMCE score for before and after instruction. Individual student pre-instruction scores can range from 0-100%, and as indicated by the FMCE scoring template, a student is said to have a Newtonian understanding of the world if they score over 60% (Wittmann, 2002). Thus, for post-instructional scores it is desirable to have students' scores beyond the 60% threshold.

Absolute scores may be of interest, but most important is that regardless of a particular student body, students should develop from having taken an introductory course in physics. Normalized gain <*g*> has been created to measure student improvement in comparison to the amount they could have improved, rather than the absolute improvement. A normalized gain accounts for variances in populations because absolute gains tend to be small for high pre-instruction scores and large for those scoring lower. This difference arises due to initially low-scoring students having much more room for growth. To normalize these absolute gains we divide actual gain by the amount of gain possible: $< g >= \frac{(postFMCE - preFMCE)}{(100 - preFMCE)}$. One of the assumptions built into <*g*> is that pre-scores correlate poorly with <*g*>, thereby allowing researchers to compare the levels of learning across courses and institutions. Much earlier work has verified this assumption for physics conceptual surveys (Hake, 1998; Meltzer, 2002; Cummings et al., 1999), although recent work by Coletta and Phillips (2005) using the FCI calls this assumption into question. Due to the volume of data from the studies showing poor correlation with <*g*>, we shall proceed as though pre-FMCE scores correlate poorly with <*g*>.

3.2.1. Overall FMCE Data

Table 7: Typical Overall Scores for FMCE[7](ILD=Interactive Lecture Demonstration, RTP=Real Time Physics, and WP=Workshop Physics)[8]

	Curriculum	N	Pre-FMCE	Post-FMCE	<*g*>
PHY 107	Lect/ILD+ Tutorial	62	19	28	0.12
Carroll College	Lect/Trad	38	20	26	0.08
U. of N. Iowa	Lect/Trad	34	25	38	0.17
Unknown	Lect/Trad	115	25	41	0.21
Unknown[9]	Lect/RTP	42	28	58	0.42
Unknown	Lect/ILD	154	15	54	0.45
Unknown	Lect/ILD	29	17	31	0.18
Unknown	Lect/ILD+ RTP	423	27	51	0.33
Unknown	Lect/ILD+ RTP	40	13	52	0.45
Unknown	Lect/ILD+ RTP	43	20	55	0.43
Unknown	Lect/ILD+ RTP	84	14	41	0.31
U. of N. Iowa[10]	Studio/WP	82	21	61	0.50
Unknown	Studio/RTP	109	31	70	0.57
Unknown	Studio/RTP	71	28	76	0.66

From the pre and post-test data in Table 7, we see that the PHY 107 students appear to start with a relatively low to moderate level of physics understanding compared to the other groups. This low level arises despite the requirement that they take a high school physics course. Over the course, the PHY 107 mean score increases by 10%, which appears in line with other traditional courses, but fails to get the majority of students beyond the 60% threshold, as the studio groups do and the lecture RTP and ILD group approach doing.

To put the PHY 107 scores more in perspective, let us consider the pre- and post-instruction FMCE medians of the course. The median shifts up from 15% to 18%, a difference of a single question correct. Contrasting the median shift from pre-instruction to post-instruction

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[7] Unclear which courses are algebra-based and which are calculus based.
[8] ILD: a curriculum for making lecture more of an active learning environment; RTP: a curriculum to replace the traditional labs with a more student driven active learning situation; WP: no longer lecture-bsed, instead a studio (lab-based) format designed to encourage continual active student learning.
[9] (Wittmann, 2002; Breen & Wittmann, 2001) course type and location unknown.
[10] Carroll College and University of Iowa data. (Saul & Redish, 1998)

with the mean shift, we see that the mean rose from 19% to 28%. The increase in mean from pre-instruction to post-instruction, with only meager gains in the mid-ranking students, as indicated by the median, shows that the higher scoring students pre-instruction tended to score higher post-instruction. Using the 60% level as the threshold for Newtonian thinking, we find that only two students (3%) scored as Newtonian thinkers before instruction, while eight students (13%) did so after instruction.

We can also consider FMCE improvement by looking at <*g*>, normalized gain. Table 7 shows <*g*> from a traditional lecture/lab/recitation course ranging from 10-20%, and may reach as high as 30% (Figure 9). We can see that the PHY 107 students fall into this same range, even with its research-based, reformed structure. Yet, other courses using research-based curriculum within the lecture-format have dramatically improved conceptual gains as demonstrated by the Unknown RTP and ILD courses. From Figure 9 we can see that the lecture-based curriculum, labeled RBC (research-based) and TRD (traditional), typically show much better conceptual development, if taught using research-based methods.

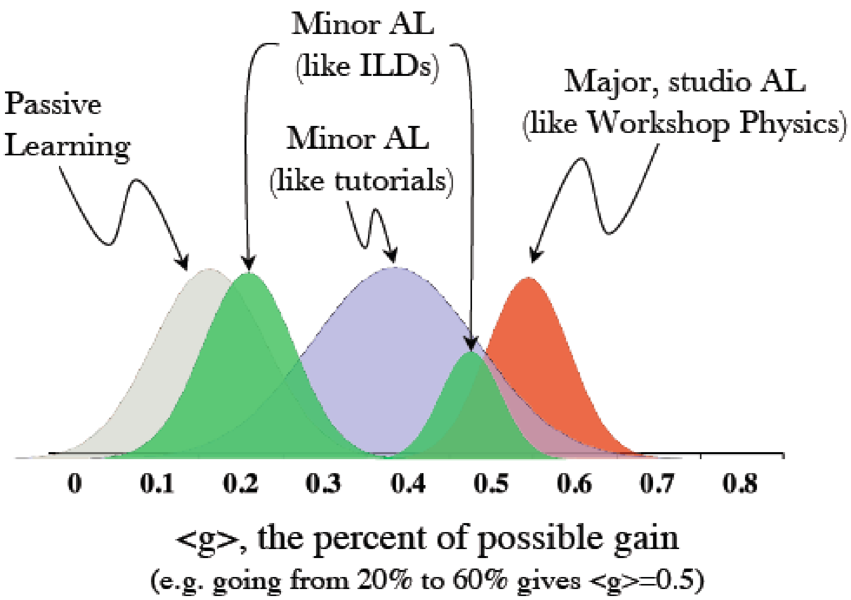

Figure 9: Distributions of FMCE normalized gain for various pedagogies[11]

Figure 9 indicates that despite the attempts to implement curricula-reform, which has been demonstrated as effective for an array of other institutions, PHY 107 students see conceptual gains on the order of a solely traditional course. Several factors may be at play here; all of these factors rely on the assumption that <*g*> can be extended as a figure of merit from the published physics education research findings. First, the graph above relies heavily on data from both calculus-based populations, which may have a very different audience than an algebra-based course: <*g*> may be inappropriate to extend to *all* intro physics populations. For that matter, the PHY 107 population may differ in significant ways from a typical algebra-based course, as indicated in sections 3.1.2 and 3.3.4 by the math diagnostic and MPEX2 data. As such, the materials used in the course, although based on the findings of the calculus and some algebra-based courses, may align poorly with the needs of the PHY 107 audience, leading to low normalized gains. These two problems of misalignment for scoring comparison and curriculum implementation may be confounding one another.

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[11] AL stands for active-learning, and minor and major indicate the relative extent of the course that has been transformed to an active-learning style (Wittmann, 2007,)

3.2.2. FMCE Cluster Data

Figure 10 shows us how the students developed in the five conceptual clusters as measured by Wittmann's FMCE scoring template. See Appendix E to view the FMCE survey and Appendix F to view the FMCE cluster legend.

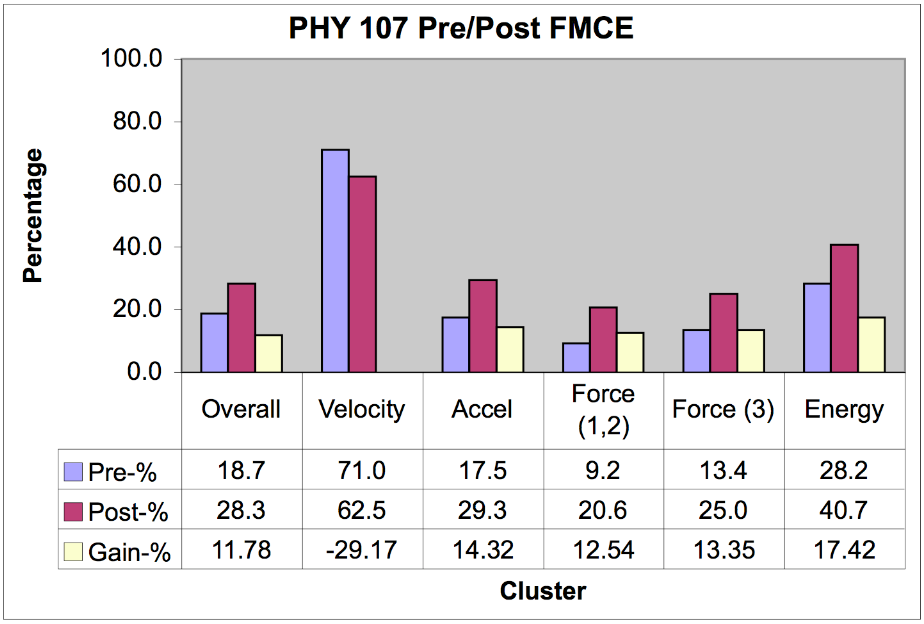

Figure 10: PHY 107 FMCE Pre/Post Instruction Cluster Results

Table 8: Pre/Post Portion of Students Scoring *Zero* on Each Cluster

	Velocity	Acceleration	Force (1,2)	Force (3)	Energy
Pre- (%)	5	63	50	66	35
Post- (%)	15	40	24	44	32
Gain- (%)	-300	37	52	33	9

3.2.2.1. Velocity Cluster

Table 9: Correct Results for Velocity Cluster

Velocity Cluster	Number of students correct	
Question number (correct)	Pre-instruction (N)	Post-instruction (N)
40 (A)	49	37
41 (F)	34	31
42 (B)	40	39
43 (D)	53	48

From Figure 10 and Table 8, we can see that as a whole the only area showing regression is the velocity cluster. This cluster demonstrates student ability to choose a correct velocity vs. time graph depicting a given scenario in words. Over the course of instruction, the number of students answering zero of these questions correct rose from three (5%) to nine (14.5%) students. The two questions causing more trouble than in the pre-test are 40 and 43. Question 40 asks students to select the graph demonstrating constant velocity. For the two common incorrect answers on the post-test five students (8%) chose the correct speed vs. time graph (B), up two students from the pre-test, and ten students (16%) selected a correct position vs. time graph (constant increasing slope), up four students from the pre-test.

Meanwhile, question 43 asks students to select the velocity vs. time graph that illustrates constant positive acceleration. The common incorrect answers for 43 were A and B, each selected by three students (5%), a decrease of 1 student for A and an increase of three students for B. These answers demonstrate varying degrees of correctness. Graph A is constant and positive, but the students seem to ignore the velocity label on the vertical axis, a mostly correct answer. Graph B takes one step further back and has the constant nature, but fails to pay attention to the vertical axis and the direction of the constant change in velocity. These errors, although undesirable, demonstrate that the students are paying attention to some, if not all, of the appropriate features of velocity and its corresponding graph.

3.2.2.2. Acceleration

Table 10: Correct Results for Acceleration Cluster

Acceleration Cluster	Number of students correct	
Question number (correct)	Pre-instruction (N)	Post-instruction (N)
22 (A)	12	20
23 (B)	6	14
24 (C)	15	20
25 (B)	7	17
26 (C)	17	19
27 (A)	10	22
28 (A)	7	19
29 (A)	7	23

Figure 10 shows a 14% normalized gain for the acceleration cluster, but let us take a look at how the PHY 107 ideas regarding acceleration actually changed. Unlike the velocity cluster, more people answered at least one acceleration item correctly following instruction than pre-instruction; the number answering no acceleration questions correct decreased from thirty-nine students (63%) to twenty-five students (40%). The common errors for the acceleration questions stem from students functionally confusing velocity and acceleration: though the most common incorrect answer for these students correctly describes the velocity of the object during the pre- and post-tests rather than the acceleration

For questions 22-26 students are asked to select the appropriate acceleration vs. time graph for a situation described in words. Although selecting an appropriate velocity vs. time graph for each question remained the majority answer on the post-test, typically 7-10 (11-16%) more students shifted toward a correct acceleration vs. time graph, rather than either confusing acceleration with velocity or ignoring the vertical axis. The only exception to this shift was question 26, which began with the highest percentage of students answering correctly within this cluster, only two new students (3%) recognized that not only must there a slope of zero, but an intercept of zero.

Questions 27-29, like two other 3-question clusters, must *all* be answered as Newton would answer them; if any are answered otherwise the scoring template counts all of them as wrong. These questions want to know how a tossed coin accelerates on the way up, at the very top, and as it falls back down. For these questions, more students moved from the thinking in terms of velocity to thinking in terms of acceleration (12-15 students (19-24%) more correct per question).

3.2.2.3. Newton's 1st & 2nd Laws

Table 11: Correct Results for Newton's 1st & 2nd Laws Cluster

Newton's 1st & 2nd Laws Cluster	Number of students correct	
Question number (correct)	Pre-instruction (N)	Post-instruction (N)
1 (B)	6	16
2 (D)	5	12
3 (F)	7	21
4 (F)	11	13
7 (B)	5	26
8 (A)	7	14
9 (A)	12	14
10 (A)	7	20
11 (A)	12	16
12 (A)	13	16
13 (A)	3	22
14 (E)	5	7
15 (E)	60	57
16 (A)	6	10
17 (E)	1	7
18 (B)	4	7
19 (B)	6	10
20 (G)	8	9
21 (E)	7	16

The Newton's 1st & 2nd law cluster checks to see how students view forces affecting the velocity of an object horizontally, vertically, and on an incline. For each plane of motion students need to interpret a verbal description for both question and answer, choosing the correct verbal answer. In addition, the students must respond to verbal description of horizontal motion by selecting the appropriate force vs. time graph. The scoring template shows these students having a <*g*> of 12.5% for the Newton's 1st & 2nd law cluster (see Figure 10). To further frame <*g*>, students scoring zero on this cluster dropped from thirty-one students (50%) pre-instruction to 25% post-instruction.

Further detail can be found by looking at individual questions in the cluster. For questions 1-4 and 7, the sled questions regarding horizontal motion (see Appendix E to view questions), the common student answers (58-89% pre-test and 29-74% post-test, depending on the question) correspond with force as proportional to velocity, as opposed to the Newtonian view that force direction and magnitude correspond with acceleration. Although the likelihood of adopting a Newtonian view increased when the sled was slowing down (questions 3 and 7). Questions 3 & 7 saw increases of fourteen (23%) and fifteen (24%) more students answering correctly. In contrast, the remaining questions only saw two to ten students (3-16%) more shifting to a Newtonian response.

The vertical motion questions used a coin toss and asked about the force just after release, at the top, and on the way back down (identical to the acceleration coin toss question). Once again the series of questions is only counted correct if students answer all three correct. For vertical motion people were more likely to keep their pre-test view that force is proportional to velocity than for the horizontal situation; however, they also began more inclined (11-21% correct, depending on the question) to think about the vertical situation as Newton would. Not surprisingly, the force acting on the way up (question 11) causes the students the greatest difficulty, while the most people answer correctly for the coin falling (question 13). Questions 11 and 13 both have nine (14.5%) more students answering constant force down (A) in the post-test, whereas only four (6.5%) more students realize that the coin has a constant force down (A) at the top.[12]

The trickiest of the three motion scenarios is the proverbial inclined plane, only now we have a toy car instead of a block. Although the situation is fundamentally identical to the coin toss, students struggle to see the situation as such. Again, students have only been counted correct if they answer all three with constant net downward force (A). The upward motion causes students

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[12] Three to five (5-8%) of the PHY 107 students scored higher when the coin toss questions asked about acceleration.

the greatest grief, and although they initially had very strong leanings toward thinking in terms of force being proportional to velocity (64.5-81%, depending on the question), there is some transition.

Although still incorrect for question 8 where the car is moving up the ramp, students answered with greater variety. Eleven students called for a net increasing force up the ramp (F), possibly confusing force with potential energy. Nine students answered saying that there was a net constant force up the ramp (E), possibly combining the ideas of force in direction of motion with a constant incline. In addition, to shifting incorrect answers, question 8 had the greatest increase in students correct, with nine (14.5%) more answering correct. Questions 9 (highest point) and 10 (rolling back down) saw increases of seven (11%) and eight (13%), respectively, more students answering correct.

The final element of the Newton's 1st & 2nd law cluster is the horizontal motion corresponding with appropriate force vs. time graphs (questions 16-21). Of the portion of this cluster, the students struggled the most with this graphing section. As appears to be the trend, the majority of students began responding to these situations as though force is proportional to velocity (40-84%, depending on the question). Answers in this cluster only improved in the range of one to nine students (1.5%-14.5%), with an increase of students being the norm. The two responses of notable (9.5-14.5%) increases in correct answers were numbers 17 and 21. These questions probed the notion of what kind of a force is needed if either the hand is removed (question 21) or told explicitly that velocity is constant (question 17).

3.2.2.4. Newton's 3rd Law

Table 12: Correct Results for Newton's 3rd Law Cluster

Newton's 3rd Law Cluster	Number of students correct	
Question number (correct)	Pre-instruction (N)	Post-instruction (N)
30 (E)	12	16
31 (E)	10	21
32 (E)	9	17
34 (E)	10	17
36 (A)	5	9
38 (A)	4	13

The Newton's 3rd law cluster utilizes cars and trucks to demonstrate collisions of large objects with small objects, collisions with equal-sized objects, and a smaller object pushing a larger object, and asks students to compare the magnitudes of the force applied by each object during the aforementioned scenarios. Unlike the Newton's 1st & 2nd law cluster, on the Newton's 3rd law cluster students were most likely to apply momentum correctly for collisions, confusing a larger initial momentum (i.e. mass*velocity) for a larger force, though this tendency decreased in favor of equal forces after instruction. With regard to pushing situations, students were more likely to consider the object causing the velocity change as having a greater force. From pre- to post-tests, students managed a <*g*> of 13.4% (see Figure 10). Additionally, those scoring zero on this cluster for the post-test decreased from forty-one students (66%) down to twenty-seven (43.5%).

For the big truck/little car collision (questions 30-32), students tended to reason as though they were discussing momentum as opposed to forces, with the object having a larger initial momentum applying greater force. After all, a larger object with a larger initial momentum does cause a larger change in velocity in a smaller object. For question 30, students overwhelmingly answered that the larger truck exerts a greater force (A), while both objects are at the same speed (77% pre-instruction & 69% post-instruction). Five more (8%) students did realize the forces are identical after instruction. The car moving faster than the big truck was a source of difficulty both before and after instruction, although there was improvement. The popular answer of not enough information (F) began with twenty-seven students (43.5%) and ended the semester with only sixteen students (26%). The second favorite alternate answer claimed the car exerts a larger force (27% pre & 19% post). With the decreases in alternate answers, eleven people (18%) more answered it correctly, representing the largest increase in correct "big meets small" collision responses. In the situation in which the truck sits still and is hit by the car, the students want to say that the car exerts a greater force (B) (53% pre & 42% post). For the car acting on the bystanding big truck, eight more students (13%) managed to answer correctly after instruction. Overall, we see a slight decline in student tendency to see forces during collisions as though considering momentum, and some moderate gains in recognizing the equality of Newton's 3rd law force pairs.

In questions with the same car crashing into the parked truck, with the truck having the same mass as the car (question 34), student tendency to see the acting object (the car) imposing a greater force on the truck increases significantly. Pretest scores for the big truck scenario had only 53%, while the same size truck had 64.5%. Post-test scores showed a similar trend with a drop to 42% for the big truck situation, while maintaining 50% for the small truck. Despite the class's tendency to favor a larger force from the car when hitting a truck of equal mass, similar numbers of students answered both of these questions correctly, differing by only one student on the pre-test and having equal numbers of correct students (27%) on the post-test.

In pushing situations where one object is more massive than the other (questions 36 & 38), the students show a strong leaning toward the object responsible for changing the rate of the other object's motion contributing more force, independent of the object's mass. Students do shift slightly away from this model of the actor doing more than the reactor (76-89% pre-instruction & 60-64.5% post-instruction). In fact, they make greater improvements with the truck acting on the car than the car acting on the truck. For the truck acting (question 38), eighteen students (29%) shift from the truck exerting a larger force and nine (14.5%) of those end the course correctly believing that the 3rd law pair magnitudes are equal. The car pushing on the truck (question 36) sees only slight improvement, with five students (8%) reorganizing their thoughts to see the force from each vehicle as equal.

3.2.2.5. Conservation of Energy

Table 13: Correct Results for Conservation of Energy Cluster

Newton's 3rd Law Cluster	Number of students correct	
Question number (correct)	Pre-instruction (N)	Post-instruction (N)
44 (B)	10	23
45 (B)	21	28
46 (A)	21	25
47 (A)	18	25

The Energy cluster showed moderate improvements, with two fewer students (3%) scoring zero, relative to the original twenty-two students (35%). With only two more students applying conservation of energy laws, the normalized of gain of 17.4% must come from those that entered having some correct ideas about conservation of energy (see Figure 10 to view cluster scores). We shall now consider some ideas the PHY 107 students have about energy.

To judge their ideas about energy students are presented with a series of hills of varying steepness and height and need to discern which hill will have give a sledder a higher speed or kinetic energy at the bottom. Although higher kinetic energy implies higher speed, students were more likely to have trouble with speed than kinetic energy when presented with hills of equal height but differing pitch (questions 44 & 45; see Appendix E). For the post-test, the total correct of each question differed by five (8%), but this disparity had shrunk from the pre-test, down from eleven students (18%). Interestingly, when the hills were the same size, students' incorrect answers tended toward the steeper hill having a greater effect (A; 34-43.5% post-test), even though this tendency certainly decreased following instruction, down from pre-test selection of 53-74%.

When the hills became different sizes and different steepness, students' tendencies differed. Pre-instruction 23-26% of the students claimed they needed more information (D), while after instruction, these numbers dropped to 11-18%. Otherwise, the students' most common incorrect answer claimed the speed/kinetic energy would be the same for the two hills (B), implying that the steepness and height difference would wash each other out (pre-& post-tests similar; 21-32%). Correct answers of the higher hill having greater velocity/kinetic energy only increased on the order of four to seven students (6.5%-11%), with more students correcting their kinetic energy ideas after instruction.

3.3. MPEX2 Results

3.3.1. SET Coordinators

As the heads of the SET program, the coordinators represent engineering technology experts with regard to the attitudes SET wishes to impart on their student body. As such, in order to appropriately interpret the SET students attitudes, it will be helpful to understand what the SET coordinators perceive as important when approaching a physics course. While looking through the MPEX2 data for how SET coordinators would like students to respond to the MPEX2 statements, three points stand out. First, one coordinator answered very differently from the others. Second, as a group, the coordinators fail to present a uniform front on several questions. Third, they are, in general, more neutral than the majority of the MPEX2 experts.

Before discussing differences among the coordinators as a whole, we should isolate one coordinator because those results skew our perspective of the group. This individual was nearly as likely to disagree with the MPEX2 experts as agree, touting 32% favorable and 29% unfavorable responses. Meanwhile, the other coordinators ranged from 58-87% favorable and 0-6.5% unfavorable. The major areas of disparity lie in the independence cluster, accounting for five of the eight questions where the atypical coordinator stands alone disagreeing with the MPEX2 creators. Recall that the independence cluster discerns the extent to which an individual/group embraces the constructivist philosophy with regard to believing that individuals need to create their own understanding, as opposed to relying solely on an authority (i.e. professor, textbook, etc.). This coordinator appears to value the constructivist philosophy less than the other three coordinators.

With the major differences accounted for in one of the four coordinators, the MPEX2 still reveals two cases where coordinators differ with the MPEX2 experts regarding what favorable SET student expectations for an introductory physics course should be. The dissention lies with questions 6 and 29. Question 6 comes from the coherence cluster stating, "Knowledge in physics consists of many pieces of information, each of which applies primarily to a specific situation." With this question, the favorable answer is to disagree, suggesting physics seeks coherence among theories and principles. The other question of interest, question 29, arises from the independence cluster claiming, "Some people have 'photographic memory', the ability to recall essentially everything they read. To what extent would photographic memory give you an advantage when learning physics?" A favorable response here implies that it only helps a little, if at all, thereby supporting the notion that students need to participate to actually make sense of physics. These dissentions among the coordinators are not problematic, but are worth mentioning because the coordinators do play a large role in guiding the School of Engineering Technology and thus the SET students in PHY 107.

A major issue of the SET coordinators' responses is the degree of neutrality, failing to agree or disagree. On can look at the statements to which at least two of the coordinators respond neutrally and find some patterns. Four of the nine statements from the conceptual cluster appear (9, 16, 28,30), one coherence-> reality statement (4), and one coherence->math statement (28[13]) (see Appendix G to view the survey and Appendix L to view the cluster legend). Recall that conceptual statements seek to elicit the perceived importance of interpreting the physical meaning of a situation when approaching a physical/physics problem. Statements 9 and 16 state, in essence, that the important thing in solving a problem is manipulating an equation (favorable is to

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[13] Statement 28 lies in the conceptual cluster as well as the coherence-> math sub-cluster.

disagree). Whereas statements 28 and 30, the only statements having three out of four selecting neutral, probe study methods and the value of studying the depth of a smaller amount of material versus making sure to cover everything at least a little bit. The remaining coherence statement (4) touches on the importance of relating personal thoughts or experiences to topics studied. Interestingly, of the four reality statements, two of four were left blank by one coordinator (not the unique coordinator discussed at length above). Discussion of the implications of these areas of neutrality will follow in section 3.3.3, comparing SET coordinators and PHY 107 Instructors' hopes for how the students expect to learn in PHY 107.

Table 14: SET Coordinator Individual MPEX2 Scores

% Favorable/% Unfavorable	87/0	81/7	58/7	32/29

Based solely upon the MPEX2 survey, SET coordinators differ from those MPEX2 creators dubbed experts in their neutrality toward conceptual understanding and connecting physics with the world around them. However, they appear fairly inclined toward students expecting to welcome the constructivist philosophy in order to learn physics (see Table 14). We will further develop this picture with the SET interview discussion in section 4.2.

3.3.2. PHY 107 Instructors

Considering the reformed-based nature of this course, we would expect the PHY 107 instructors to embrace the constructivist philosophy and align well with the MPEX2 experts on how they would like students to respond to the given statements. Looking at the instructor data, in general, the instructors respond as an MPEX2 expert would want their students to respond; however, like the SET coordinators, the instructors have one unique respondent that skews the view away from the experts.

Let us examine the trends from the single instructor, aligning 58% favorably with the MPEX2 experts and 29% unfavorably. The remaining instructors ranged from 74-100%

favorable and 0-7% unfavorable. Because only 13% of the isolated instructor's responses are neutral, while 29% are unfavorable, we will seek trends in those unfavorable responses. Interestingly, all nine of the unfavorable responses fall under two clusters: concepts and independence->epistemology (see Appendix G to view the survey and Appendix L to view the cluster legend). These three concept-statements (5, 16, 24) claim that formulas and finding equations are basically what physics is about. For each of these statements, an unfavorable response agrees with the statement, thereby undermining the importance of understanding and utilizing the physical interpretation of the situation to solve a problem. As for the six epistemological statements (2, 11, 12, 22, 29,32), these statements claim that students wishing to do well in physics students had best avoid trying to understand and instead focus only on finding and making sure to use the given ideas/answers from an authority figure (professor, book, better student, etc.). Aligning with these statements counters the constructivist notion that to do well and actually have useful knowledge for future use, students need to make sense of and restructure ideas to own them. Thus, agreeing with these authority-driven statements are unfavorable from the MPEX2 expert perspective.

The only other two unfavorable responses from the five instructors came from one other individual. This instructor disagreed with MPEX2 experts regarding whether students should try to connect their own experiences with the physics they're learning (coherence->real; #4), and whether a student should have an awareness of how well they did on an exam before talking to anyone else (independence->personal metacognition; #17). No trends in neutral responses appeared.

Other than the single instructor (a TA) responding rather unfavorably to conceptual statements and highly unfavorable toward epistemological statements, the instructors align well the MPEX2 experts.

3.3.3. SET Coordinators and PHY 107 Instructors Comparison

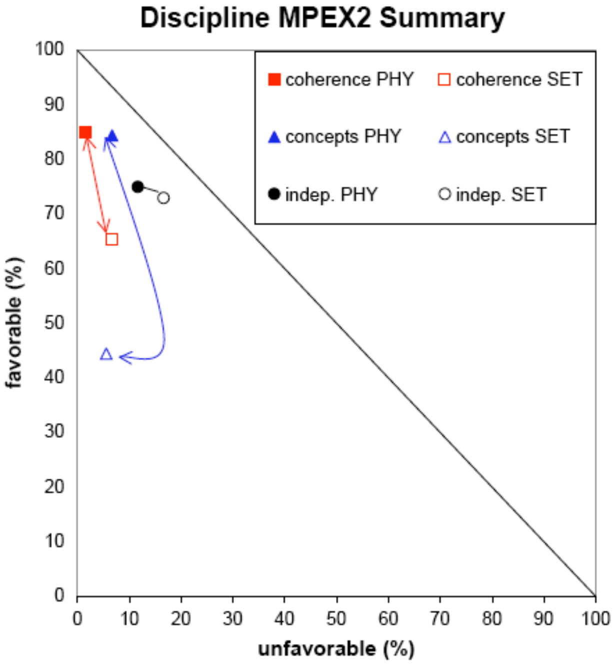

Figure 11: Differences of MPEX2 Desired Responses by Discipline

As stated previously, the creators of the MPEX2 have calibrated the responses to their survey as favorable or unfavorable based upon sampling a population of physics professors, who they felt fostered the constructivist ideals of a practicing physicist within their course. For this study, we have two disciplines, engineering technology and physics, both of whom may have differing expectations of what is a necessary and valuable approach based upon the ideals of their discipline. It is possible that the expectations these disciplines have for how a student should feel he/she needs to interact with the PHY 107 course align, but it is also possible that the continual clash of applied versus theoretical disciplines, suggested by Donald (2002), exists here.

We now contrast the two disciplines with regard to our MPEX2 data to see how these local "experts" in their respective fields align. Figure 11[14] shows us that the PHY 107 instructors align well with the MPEX2 experts with how they would like students to respond to MPEX2 statements, although the independence cluster has less favorability and is higher in unfavorability, which is accounted for by the single instructor's dissention with MPEX2 expert epistemological expectations. We see that the independence clusters of SET and PHY match fairly well with each other; however, the SET coordinators appear much more indifferent toward some of the

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[14] To view graphs of the MPEX2 sub-clusters, see the Independence and Coherent graphs in Appendix O.

constructivist ideals. We also see roughly 20% lower favorability regarding the extent SET would like their students to value the connection of ideas (coherence) within physics, and a 40% lower rate of favorable SET responses for how they would like their students to respond regarding the extent the physical situation should be considered when solving problems (concepts). Note that neither of these differences arise as a consequence of increased unfavorable responses— they arise from a higher rate of neutral responses.

This neutrality could suggest several things. One, SET faculty may be saying that although they may wish students to answer more in one direction than another, the SET faculty's pragmatism may trump their ideals. Or, two, they may truly be indifferent toward these ideals that a first year SET should concern themselves with trying to make connections among ideas and working with knowledge of the physical situations to guide the problem-solving process. These issues are revisited in section 4.1.

3.3.4. Students

Table 15: SET Students MPEX2 Scores Compared to Local Experts and Other Lecture-based Physics Courses

Scores from MPEX2								
%F/%U	Overall	Coh	Conc	Ind	Coh-Math	Coh-Real	Ind-Epist	Ind-Pers
PHY 107 Instructors	83/7	85/2	84/7	75/12	93/0	80/5	73/12	80/7
SET Coordinators	65/11	65/7	44/6	73/17	59/0	71/7	75/15	67/17
SET Students Pre-instruction	46/32	49/29	24/46	52/31	36/36	65/12	45/35	73/11
SET Students Post-instruction	40/36	42/30	29/46	40/37	36/39	55/19	34/40	57/22
Typical Scores from *Reformed* Lecture-based Course Original MPEX[15]								
Pre-instruction	55/21	54/22	41/33	55/23	68/14	66/11	n/a	n/a
Post-instruction	50/24	51/25	42/32	51/25	62/17	60/15	n/a	n/a
Typical Scores from an from *Traditional* Algebra-based Lecture Course Original MPEX[16]								
Pre-instruction	55/19	46/29	36/34	46/33	61/12	72/6	n/a	n/a
Post-instruction	47/33	47/36	37/40	37/47	56/26	50/21	n/a	n/a

Table 15 highlights the range of expectations that our local experts would like to see students have for how they need to interact with the physics course to be successful. In addition, the table illustrates examples of pre-/post-instruction responses to the original MPEX from both reformed lecture=based courses and a traditional lecture-based course (see Appendix L for the cluster legend). Table 15 gives us a means to discuss the data from the PHY 107 students based-upon some typical results.

Redish et al. (1998) note that beginning students typically agree with MPEX experts for 40-60% of the statements (favorable) and disagree with the MPEX experts 20-30% of the time (unfavorable). We can see that in order for PHY 107 students to obtain their pre-instruction overall favorable mean (46%), the majority of the students lie on the low end of typical individual

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[15] Typical scores based upon the averages of the three lecture-based reform courses presented in Redish et al (1998). Note all of these appear to be calculus-based courses.

[16] Scores represent Carroll College, a small liberal arts college (Saul & Redish, 1998).

pre-instruction favorability scores. The PHY 107 pre-instruction overall unfavorable mean (32%) resides above the typical individual range of scores. This combination implies that PHY 107 students enter a course implementing research-based constructivist pedagogy, with not only less expectation for working constructively (actively) than the typical group, but also, more opposed to the idea.

Interestingly, when we look across the clusters of the three groups of students pre-instruction responses shown in Table 15, PHY 107 only differs significantly from the other courses in one over-arching cluster (concepts) and one-sub-cluster (coherence->math). These clusters are similar in that the concept cluster's favorable view stresses the importance of understanding and utilizing theory as guidance for solving problems, and the favorable math cluster sees equations as a simplified way to represent a physical situation. For both of these clusters the unfavorable view focuses on using and manipulating formulas as important, independent of considering the actual physical situation.

The post-instruction scores are similar to the pre-scores except that they decrease for most every cluster, regardless of instructional type. [17] The typical exception for research-based reformed-instruction is the conceptual cluster. Although the pooled data in Table 15 from the reformed instruction fails to show the typical course changes present before averaging, favorability in clusters tend to decline on the order of 5-10%, and unfavorable responses increase by roughly 3-5%.

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[17] Workshop Physics, studio format (lab-based as opposed to lecture-based), is the only curriculum/course structure showing increases on the majority of MPEX clusters post-instruction (Saul & Redish, 1998).

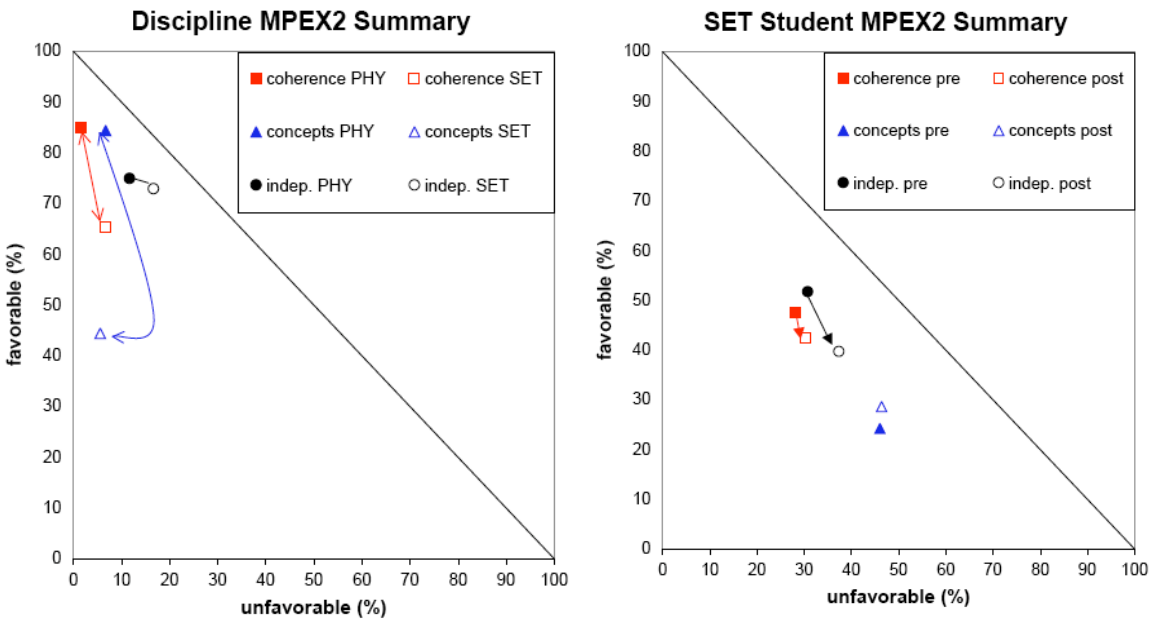

Figure 12: Comparing SET Students with the Local Experts

From Table 15 we see that the SET students' constructivist expectations only drastically differ from other traditional lecture-based populations in their value of concepts and the coherence of math with the physical world. Now, if we wish to consider the SET coordinators as the experts, then we should be comparing the SET students with them. Table 15 and Figure 12 show that the SET students align *much* better with the SET coordinators responses than those of the MPEX2 experts.

3.4. SAT

The School of Engineering Technology currently has minimum SAT admission guidelines in place: 520 math and 530 verbal (SET Coordinators, personal communication, 2006). These minimum guidelines resemble the means of the UMaine's entering first year students from the last 16 years: approximately 540 for math and 545 verbal. What we find for mean SAT scores in the PHY 107 class are 555 math and 498 verbal. These scores imply that although verbally SET students may have a small disadvantage to the average UMaine student, their math skills should actually be slightly superior. Furthermore, the College of Engineering mean SAT scores are around 625 math and 570 verbal. If we factor out SET, who account for one-third of the population and interpolate from the PHY 107 mean SAT scores, we get the typical engineering students means at approximately 660 math and 606 verbal. This illustrates that although the SET students, as measured by the SAT, are similar to the average UMaine student, the typical engineers have scores higher than the SET student by over 100 points in both verbal and mathematic measures.

(http://www.umaine.edu/ois/fact_book/Admissions/admissions.htm, n.d.).

3.5. Statistical Analysis

The purpose of this study is to develop a baseline representation of this previously unstudied PHY 107 population; therefore, all analysis used linear regression modeling instead of performing a comparative analysis based upon previous data (e.g. t-tests). The statistical software package R performed all calculations (http://www.r-project.org/). Before testing any models for significance and explanatory power, the residuals needed to be tested to make sure they meet the assumptions for normality and equal variance. The residuals are distributed normally means that the linear model has the majority of the estimated points within a smaller range of error from the actual data with the amount of data greatly diminishes the farther values get from the estimated values. The second criterion for accepting a model is that the variance[18] in the data from the predicted model is equally distributed both above and below the predicted values throughout the data set.

In the measures discussed below, we present information comparing several elements measured in the study. The goal is to understand what leads to variance in the data. We will consider *p*-values less than 0.05 as statistically significant. A *p*-value of 0.05 allows a 5% chance of accepting a predictive model that fails to actually explain variance in a data set of interest. The second element we will need to make sense out of how much variance is explained by the data is a scale to tell us if we have large or small explanatory power. For this scale we will discuss effect

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[18] Variance means the distance the data is from the predicted value, both positive and negative.

sizes. Effect size will be considered small if $R^2 > 0.01$; moderate if $R^2 > 0.06$; and large if $R^2 > 0.14$(Aron & Aron, 2003). [19] The R^2 value tells us the proportion of variation explained by our dependent variable; a small effect size explains greater than 1% of the variance in the independent data, a moderate effect size explains more than 6% of the variance in the independent variable of interest, and a large effect size explains at least 14% of the variance in the independent variable of interest.

3.5.1. How well does the UMaine's Math Placement Exam explain the variance in the Math Diagnostic Clusters of concern to PHY 107 Instructors?

Table 16:Math Placement Exam and SAT as Diagnostic Indicators

	p-value	R^2
Math Diagnostic *Clusters* vs. Math Placement	2.27E-4	0.244
Math Diagnostic *Clusters* vs. SAT Math	6.59E-7	0.370
Entire Math Diagnostic vs. Math Placement	2.55E-6	0.366
Entire Math Diagnostic vs. SAT Math	1.14E-10	0.540

Above in Table 16, we can see that although the Math Placement Exam serves as a reasonable indicator for discriminating how well student will perform on the Math Diagnostic clusters and the Entire Diagnostic, the math portion of the SAT serves as a better indicator in both regards. The difference in the ability to explain the variance in the Diagnostic clusters is 24.4% for the Placement Exam and 37% for the SAT, with all tests statistically significant ($p<0.05$). For the entire Diagnostic the SAT explains 17.4% more of the variance than the Math Placement exam. Due to the scale difference on the SAT we can't directly compare the slopes, but we see that the slope of the model is greater for the Math Placement Exam and the entire Math

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[19] The square root of variance (R^2) is the Pearson correlation coefficient (R).

Diagnostic than for the clusters. This greater slope implies that the math placement test better aligns with the questions from the Diagnostic not part of the clusters, than those in the clusters.

3.5.2. Does normalized gain <*g*> on the FMCE correlate with pre-instruction FMCE scores?

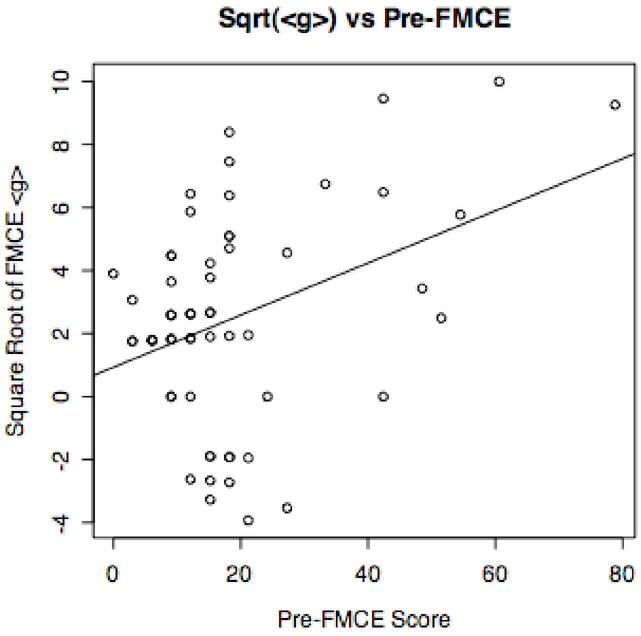

Figure 13: Scatter plot of Sqrt<g> vs Pre-instruction FMCE scores

Using normalized gain as a score illustrating development due to instruction implies that pre-test scores correlate poorly with the percentage of possible gain a student reaches. What we actually found was that the pre-instruction FMCE scores significantly ($p = 0.002$) accounts for 14.4% (R^2=0.144) of the variance in the square root of <*g*>[20], illustrating a large effect size. To look at this from another perspective, we can say that we have a Pearson's correlation coefficient (R) of 0.38. We can conclude that PHY 107 students having a better understanding of physics when they enter the course, as measured by the FMCE, are more likely to have greater improvements within their possibility for improvement (i.e. normalized gain) than those with lower scores.

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[20] I took the square root of the absolute value of all normalized gain scores and then added the negative back to those that began negative, in order to maintain a scaled distribution, while keeping all of the data.

3.5.3. Is there anything that correlates better with <*g*> on the FMCE than pre-instruction FMCE score?

Now, we have shown that based on the correlation between <*g*> and pre-instruction FMCE scores. We can ask if any of the other measures we have the capability of explaining the variance in <*g*> any better than the pre-test scores.

Table 17: Indicators for square root of <*g*> on the FMCE[21]

	p-value	R^2
FMCE-Pre	0.002	**0.144**
MPEX2 Favorable Pre-	0.005	0.126
MPEX2 Favorable Post-	0.029	0.077
MPEX2 Favorable Pre- Coherence Cluster	0.004	**0.128**
MPEX2 Favorable Post- Coherence Cluster	0.015	0.096
MPEX2 Favorable Pre- Concepts Cluster	0.002	**0.147**
MPEX2 Favorable Pre- Coherence + Concept	3.79E-4	**0.269**
MPEX2 Favorable Post- Coherence + Concept	0.031	**0.141**

Table 17 shows the only data beyond the FMCE pre-instruction score that are statistically significant and serve as indicators for <*g*>. The MPEX2 favorable coherence and concepts cluster scores and combined coherence/concept cluster scores highlighted in bold are the only indicators with greater explanatory power of the variance in <*g*> than the pre-instruction FMCE scores. The pre-instruction MPEX2 favorable coherence/concepts explains 27% of the variance in <*g*> and post-instruction MPEX2 favorable coherence/concept cluster explains 14% of the variance in <*g*>. The explanatory power of these clusters together implies that students either entering or leaving PHY 107 with a stronger belief that physics ideas need to be connected and consistent *and* who seek understanding of the underlying ideas and concepts are more likely to make larger relative improvements (<*g*>) in Newtonian thinking than those entering the course already closer

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[21] See Appendix M to view results from all other data collected in this study, which failed to show statistical significance. The square root has been applied to meet the assumptions for residuals in linear modeling.

to a Newtonian understanding of physics. This finding implies that instructional time may be better spent focusing more on developing attitudes toward learning, as measured by the MPEX2, rather than solely on developing Newtonian thinking because skills measured by the MPEX2 better align with *learning* in physics class than previous Newtonian thinking alone.

3.5.4. What best explains the variance in pre-instruction FMCE scores?

Table 18: Indicators for square root of pre-instruction FMCE scores[22]

	p-value	R^2
Math Diagnostic Clusters	0.054[23]	0.060
Entire Math Diagnostic	0.003	0.136
SAT-Math	0.010	0.117
SAT-Verbal	0.010	0.117
MPEX2 Favorable Pre-	1.08E-5	**0.280**
MPEX2 Unfavorable Pre-	6.67E-4	0.177
MPEX2 Favorable + Unfavorable Pre-	2.52E-4	0.2795

Table 18 shows that the SAT math & verbal and the Entire Math Diagnostic are very near levels of large effect size (R^2>0.14), while the Math Diagnostic clusters important to the PHY instructors are not statistically significant. Meanwhile, the pre-instruction MPEX2 data accounts for 14% more of the variance in pre-FMCE scores than any of the other data.

Table 19: Pre-MPEX2 clusters as indicators for square root of pre-instruction FMCE scores[30]

	p-value	R^2
MPEX2 F & U Pre-Coherence + F & U pre-Independence	2.13E-4	**0.342**

Upon closer inspection of the MPEX2 pre-instruction scores (Table 19), we can see that the Coherence and Independence clusters in their entirety explain the greatest amount of variance in pre-instruction FMCE scores— 6% more than if the Concepts cluster is included in the model.

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[22] See Appendix N for full list of indicators.
[23] Note: The math diagnostic clusters is the only indicator failing to be significant at the 0.05 level.

3.5.5. What best explains the variance in post-instruction FMCE scores?[24]

Table 20: Pre-Instruction indicators for square root of post-instruction FMCE scores

	p-value	R^2
Entire Math Diagnostic	0.010	0.104
SAT-Math	0.006	0.131`
MPEX2 Favorable Pre-	4.66E-6	0.297
MPEX2 Unfavorable Pre-	0.003	0.134
MPEX2 Favorable + Unfavorable Pre-	9.57E-5	0.304
MPEX2 Favorable Pre-Coherence Cluster	4.08E-6	0.300
MPEX2 Unfavorable Pre-Coherence Cluster	6.32E-4	0.178
MPEX2 Favorable Pre-Concepts Cluster	1.98E-4	0.208
MPEX2 Favorable Pre-Independence Cluster	0.006	0.118
MPEX2 F+U Pre-Coherence + F Pre-Concepts + F Pre-Independence	2.51E-4	0.338

Table 20 shows us that of all the pre-instructional data the MPEX2 best explains the variance in the post-instruction FMCE scores, as it did for the pre-instruction FMCE. Interestingly, for the post-instruction FMCE all favorable cluster scores and the Coherence clusters unfavorable scores form the model to best explain the post-instruction FMCE scores.

Post-instruction MPEX2 scores are the only data we have for post-instructional indicators for post-instruction FMCE scores.

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[24] All Indicators explaining less than 10% of the variance can be found in Appendix O.

Table 21: Post-Indicators for square root of post-instruction FMCE scores[25]

	p-value	R^2
MPEX2 Favorable Post-	0.003	0.140
MPEX2 Unfavorable Post-	0.010	0.105
MPEX2 F & U Post-	0.027	0.145
MPEX2 Favorable Post-Coherence	9.97E-4	0.166
MPEX2 Unfavorable Post-Coherence	0.002	0.146
MPEX2 F+U Post-Coherence	0.006	**0.191**

Table 21 illustrates that the post-instructional MPEX2 scores fail to have the same level of explanatory ability as pre-instruction. However, what is interesting is that those students having more favorable and less unfavorable coherence post-test scores performed better on the post-instruction FMCE.

3.5.6. What best explains the variance in pre-and post-instruction MPEX2 scores?[26]

The only two indicators of note for the MPEX2 are the FMCE and SAT-verbal. For pre-instruction MPEX2 scores, the FMCE has a large effect size ($R^2>0.14$) for nearly all pre-instruction MPEX2 clusters, whether looking at favorable or unfavorable responses. Post-instruction MPEX2 scores, on the other hand, were only explained by the FMCE (pre-instruction, post-instruction, and <*g*>) with a medium to large effect size ($0.06 \leq R^2 \leq 0.14$) and all other pre-instruction indicators had little explanatory power for post-instruction MPEX2 scores. One point of interest is that the SAT-verbal had a large effect size ($R^2>0.14$) on nearly all MPEX2 pre-instruction clusters, but over the course of a semester, the SAT-verbal scores no longer had a statistically significant correlation with (post-instruction) MPEX2 scores.

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[25] All post-MPEX2 data explaining less than 10% of the variance can be found in Appendix O.

[26] See Appendices P & Q to view statistical analysis results of all indicators for pre-MPEX2.

3.5.7. Statistical Summary

Coming from this statistical analysis we have several important findings. First, despite Meltzer's (2002) findings regarding math skill correlating well with conceptual gains and the SET and PHY 107 community's attention to these students' math skills negatively impacting their learning, the Math Diagnostic scores and the SAT math scores account for only a fraction of the variance in students normalized gains. Meanwhile, students' pre-instruction scores correlate well with normalized gain (R=0.38) following Coletta & Phillips findings (2005) and contrary to findings from other studies (Hake, 1998; Cummings et al., 1999; Meltzer, 2002). Attitudes, however, correlate as well or better than the pre-instruction FMCE scores: favorable MPEX2 pre-instruction coherence & concept clusters combined correlate better (R=0.52), while favorable post-instruction (0.38) coherence & concept clusters combine to correlate as well as pre-instruction FMCE scores with normalized conceptual gains <*g*>.

Chapter 4: Interviews

An extensive series of interviews with the SET director and coordinators, PHY instructor and teaching assistants, and the students in PHY 107 course give more detail about the goals of the SET program in requiring PHY 107, the goals of the PHY 107 teaching staff, and the mindset of students taking the course. The following description of interview results gives an overview of what is expected of the SET students and the environment in which they work. An overarching theme of the administrators and instructors is the importance of students developing sense-making skills, to which the students respond with mixed reactions about and struggle to understand where to begin the sense-making process. The process of choosing interviewees has been described in Chapter 2.

4.1. SET

As with the math instructor's recognition of students' strengths and weaknesses, the SET director and coordinators commonly recognize the strengths and weaknesses of students as measured by the FMCE and MPEX2.

4.1.1. Director

4.1.1.1. Who are the students that enter SET?

According to the Director, students enter SET through one of two paths; they either self-select the SET program or they fail to meet the College of Engineering's SAT and/or class rank requirements. The SET guidelines fall at 530 verbal and 520 math for SAT scores. The majority of the SET population comes ranked in the top 20-40% of their high school class. Those self-selecting students are filtered through the University admission's office; however, the Director must review those failing to meet the SAT or class rank standards for the SET or those deferred by the College of Engineering. As the Director filters through those students that failed to meet the admittance standards, the overall academic picture is important, and must include trigonometry and physics, but above all, the Director seeks evidence of a willingness to work hard as illustrated by the students' entire application package.

Unfortunately, although the students can be incredibly hard workers, they have little interest in learning anything they fail to perceive as valuable to their interests or future plans. Thus, convincing these students of the importance of learning the fundamentals remains difficult.

4.1.1.2. What separates engineering technology majors from engineering majors?

According to the Director, the College of Engineering and the SET are both ABET-accredited and, as such, EET and MET majors become electrical engineers and mechanical engineers in the working world; engineering technology is not an entirely separate profession. But the way engineers and engineering technology majors begin as undergraduates is very different.

Due to the variety of high school experiences of those entering the SET, students' first year of courses are pre-calculus-based to allow those lacking a proper engineering background to "catch up," while the majority of the typical engineers jump directly into calculus-based courses. The second significant difference lies in the hands-on nature of the SET program. SET students tend to be more concrete and many "come for the hands-on nature. That's how they learn." Due to this nature, the SET program introduces SET courses the very first semester, unlike their typical engineering counterpart that does one-and-a-half years of fundamentals first. In addition, SET tries to build in hands-on components to all their courses, in order to prepare students for functioning in the workplace without a large transition as well as to cater to their student body's preferences.

4.1.1.3. What do the SET students need from physics?

The Director sees physics as an opportunity to learn some fundamentals about how the world works and developing problem solving strategies and schemas. Again, physics instructors will have trouble communicating the value of what the students will learn, due to the students' pragmatic stance toward education, but the SET and physics instructors should try to convey its value whenever possible.

4.1.1.4. Why have students take pre-calculus and physics simultaneously?

PHY 107 is algebra and trigonometry-based and these SET students have all had algebra and trig before. In addition, they have also had a physics course. If students had never seen algebra or trigonometry before, then that would be another story, but PHY 107 instructors are merely asking them to use what they have already studied. Putting physics off would be problematic for the SET, particularly with the concrete nature of their student body. If physics shifted back a year or even a semester, then the SET courses would also shift back. This idea counters the SET goal of having students take SET courses right away.

4.1.2. Coordinators

A major element, which the SET battles through all four years, is their students' attitude toward learning. One major difference between the SET student and the straight engineer is the "I want to build this sucker today. How do I do it?" attitude. Although this attitude is one of their strengths, the pragmatic nature of SET students makes it difficult to sell them theory's value for reflecting and predicting. Nonetheless, "[SET] is working really hard to bring these very physically oriented students to this prediction area." "For some students, it's an easy sell. 'You need this theory to do this work. But for others, it's a very hard sell because they don't know what the end work is, really." There is "this idea that 'if I have a number, I don't need to know how to get there.' Learning in class is not a spectator sport…they must understand that the work is more important than the right answer." "[The SET certainly] understands the difficulty that's faced in making these students aware that there is a variety of skill sets that go into comprehension."

4.1.2.1. How would you describe SET students?

4.1.2.1.1. EET

EETs are visual learners that like to see results and actual physical things happening. Labs help them a lot, but you have to make sure that labs are related to what you are doing in class if you want them to get it. EETs are a hands-on group. Thus, a lab is present in every course. The key to helping them learn is getting their interest, and not necessarily with something they like. For instance, the personable touch of knowing who your students are goes a long way with this group.

The best EET has a will to learn. With a will to learn, any deficiencies can be worked out with time. Unfortunately, the students "want to earn. They don't necessarily want to learn." Despite the department's struggle to develop them toward reflection, many just want to get by, "'I don't want to understand it. I just want to know how to solve it.'" Many of them fail to see the beauty in how you get to an answer. It is certainly not unusual for a student to show up and never have opened a textbook.

4.1.2.1.2. SVT

Surveying majors come to surveying because they have interest in surveying and like the outdoors, discarding the need to hook them. The element seeming to separate successful from the unsuccessful SVT student is the degree of dedication upon arrival to the program.

4.1.2.1.3. CMT

The ideal CMT comes with a willingness to work hard, and good math & reading comprehension skills. Reading comprehension comes into play with large role of communication necessary for these students' futures. The students that actually arrive in the major have a willingness to work, their major strength, learn by doing, and think fairly logically, with a reasonable approach to problem solving. Sadly, CMTs also come only wanting to know what they *have* to do in order to get their desired grade in a course. An education seems to interfere with their desire to get out of the program and begin their high-paying job. As for physics, CMT students, as a group, seem to see physics as merely a hurdle that they must get over, even if just barely, with no reason to ever look back.

4.1.2.1.4. MET

METs "come on purpose." They are, literally, a very hands-on bunch interested, and many of them with a background in making and fixing things. The METs tend to have strong notions about what interests them and what they do and do not want to do. The majority seeks very practical knowledge. Unfortunately for the university setting, the typical MET had a previous life and tends to attach only moderate to low-value to academics. Although bright enough to slide by with little effort in high school, their attitude to academics and their lack of experience actually studying leaves results in many METs arriving with poor study skills. These study skills compound when they run into the wall of language meeting symbols. Some can do something, but fail to explain why, while others can explain, but cannot even begin to do it. The final downfall of this group comes in conjunction with their strong notions about how things should be. They tend to be *incredibly* reluctant to adjust incorrect previous knowledge, even as 4th years, and likewise, resist change in people and practices that are outside what they perceive to be normal or right.

4.1.2.2. What do SET students need to gain from a physics course?

The majority of the Coordinators have little interest in the PHY 107 course weeding out students. They place a great deal of confidence in the admissions process. Despite confidence in admissions and their Director, they realize that some of the students will fail PHY 107 either because the SET has failed to do their job or "the students themselves are not doing their job." Due to the similarities in rigor and necessary math skills, SET recognizes that some students will fail, much like they would fail if those same students were in an SET course. "There is a population of maybe 5-10% of the students who are not going to achieve. I have come to accept that." "Our goal is to bring everybody that's willing to make the effort and that has the correct background to a set of standard levels."

When it comes to the particulars about the physics course, the major thread through the Coordinators reveals a lack of awareness of exactly what they desire a physics course to offer their students. Credentialing, accreditation, and developing intuition and skills for the future compose their general expectations for the course.

Seeing PHY 107 as a skill-building venue, the Coordinators feel that their students should develop their mathematics skills. In particular, they should develop the ability to translate word problems or actual situations into a mathematics problem. The translation of words to symbols may be a weakness of the students, but is a skill highly desired by SET. For that matter, working back from symbols to words should come into the picture, as only 20-30% of SET students' actual work within their profession involves calculation. Verbal communication makes up much of the remaining portion despite these students' reluctance believe the merit in verbalizing mathematics.

The Coordinators have some specific elements of interest for future coursework. MET and CMT Coordinators noted the value of the free-body diagram and preparation for statics. Though the MET Coordinator briefly mentioned the value in the entirety of mechanics, the only element the MET coordinator discussed explicitly was the free-body diagram. All coordinators mentioned the importance of developing physical intuitions and rounding out an education; however, it seems that the crux of having a physics course stems more from credentialing and ABET accreditation.

SET *strongly* encourages all of their students to sit for their respective professional licensure exams. The surveyors take the Fundamentals of Land Surveying (FS) Exam to begin this licensure process, but physics and scientific process only represents a small fraction of the material on the FS Exam (see Appendix R). Meanwhile, the remaining majors take the Fundamentals of Engineering (FE) Exam. This exam covers an array of topics that may be part of an introductory physics course, and for the CMT major, in particular, physics is the only time they see some of the material covered (see Appendix S).

In order to be an ABET-accredited engineering technology program, the SET must have their students take an introductory science course, which "includes laboratory experiences, which develop expertise in experimentation, observation, measurement and documentation." The more general skills students must apply serve as a basis to help clarify what ABET seeks from programs they accredit.

An engineering technology program must demonstrate that graduates have[27]:

- An ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology
- An ability to conduct, analyze and interpret experiments and apply experimental results to improve processes
- An ability to apply creativity in the design of systems, components or processes appropriate to program objectives
- An ability to function effectively on teams
- An ability to identify, analyze and solve technical problems
- An ability to communicate effectively
- A recognition of the need for, and an ability to engage in lifelong learning
- A commitment to quality, timeliness, and continuous improvement (ABET, 2006)

Interestingly, many of the ABET requirements align well with effective pedagogical methods promoted by physics education research findings.

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[27] See Appendix T for all ABET criteria in this list. I have only included those potentially relevant to an introductory physics course.

4.1.2.3. The nature of a lab as SET sees it

Due to the hands-on nature of the SET and their students, labs and the use of labs came up during several coordinator interviews. “One of the questions to ask is how many of the students have done those [labs] in high school. Because what happens is if they’ve already done something and they can’t connect some new learning to it, it’s hard to convince them that they need to do it again.”

If the nature of a lab is to give the students hands-on application, then they must understand why they have done what they have. In SET labs, “I’m hearing that they don’t have time to process and internalize the outcomes. I think that’s a real issue.” SET majors will have to troubleshoot real situations on a regular basis. Therefore, they need to understand why it did or did not work, and recognize when it really is not working. “I don’t think that they get that you need data to support a conclusion. “ These students struggle very much with the idea of data-driven outcomes. The better they can recognize when things have run awry, the more they can learn. “If a lab works perfect every time you get not that much out of it. The more it doesn’t go like I said, the more they learn. They [also] have the satisfaction of finding it for themselves.” “The other thing is that in an academic setting, they’re being graded on outcome,” which harbors the notion that data must support your prediction rather than data driving an alteration to an original prediction. “[T]he use of data to compare to an expected conclusion— does the data match the conclusion and being able to decide if that’s true and what does it imply, is a big piece for us.”

4.2. PHY 107 Instructors

As with the SET coordinators, PHY 107 instructor responses show many similarities with their MPEX results. Also, they show an awareness of student strengths and weaknesses. As before, quotes are those of the individual interviewees, and non-quoted material summarizes longer discussions.

4.2.1. Lecturer

4.2.1.1. How do you view the SET students?

"I…[am] trying to figure out the difference between ETs and [typical] engineers…The non-technology type likes to be designing things over a computer possibly…The ET person wants to get their hands dirty. They probably don't want to go thinking about what they're doing. They probably just want to go do it." "…[A]s a whole group, they really don't want to think a lot if the can help it. They like to get by."

There seems to be very marked difference between the SET students and your typical engineers and scientists taking an introductory physics class, regardless of whether we are speaking of the calculus or algebra-based groups. The major differences appear to lie with their math skills, study skills, and general attitude. For a brief period in the 1990's when PHY 107 was combined with PHY 111, the standard algebra-based course, "I've been told that…the Technical Physics course [SET students] made up the bottom third of the class. A few got into the high parts, but most of them were in the bottom third."

Let us begin with their math skills looking for potential reasons for the disparity. "There is a wide range of mathematical abilities." As a group the major problem areas that the Lecturer has seen lie in Algebra, trigonometry, and where some more fundamental mathematical skills intersect with algebra and trig. Some of the specific processes that tend to cause problems are solving simultaneous equations, reasoning across the equals sign, working with anything that involves a variable in the denominator, adding fractions, applying meaning within an equation, and working with symbols as variables/constants when they are not x and y. "Reasoning across the equal sign" means to apply operations to a whole system as opposed to only a single part. "Applying meaning within an equation" refers to their ability to regurgitate a formula, but failure to recognize how each element affects the outcome, particularly if some of the values are negative.

"I wish they'd come with better study skills…Too many of the students in the class want the answers to the physics problems. So they join the tutoring program and find out it's about study skills and they get lost because they don't want to spend the time learning how to study." There's this attitude that "'if it can't help me with doing the physics problems its probably not going to benefit me. And doing the physics problems means giving them the solution…Again, it's this resistance to thinking and doing it yourself."

When the Lecturer asks a struggling student, "Do you know how to do the [problems] that you got wrong?"

"Well, no," the student replies.

The Lecturer volleys back, "Well, why not?"

"Well, I thought that 70% of the test would be something I could do."

The combination of attitude and inexperience with studying appears to really hurt these students in physics. The attitude extends beyond just their approach to the material. The SET students react differently with each other than the typical group of engineers and scientists. In PHY 111 and 121, you can expect a certain amount of peer pressure of students wanting to keep up with, outperform, or outwork their classmates. This pressure seems to help the students extend themselves to try to learn the material, whereas in PHY 107the Lecturer perceives an anti-intellectual tone.

The final element that concerns the Lecturer with regard to the PHY 107 population is their belief that they do not need to justify themselves and communicate the ideas that they think they understand. "These people don't think they're going to have to get up in front of a group of people and make a presentation…, but engineers are always making presentations…They don't realize that there's a lot of stuff back in the office that has to get done." This repulsion towards discussion and communicating ideas makes instruction a difficult at times.

4.2.1.2. What are the most critical elements SET students need from physics?

"I'd like them to [leave] more curious of the world around them and not be afraid to ask the question, "Why?" about anything." "I think that engineering is a specialty, an application of physics…[Physics] is important to their career. It may not be that they need F=ma, but they need to understand the process of building models, logically connecting things, …and being able to use mathematics along with definitions to come to conclusions…I'm expecting that they'll be confronted with problems, I'm not sure how often, but I'm sure many times in their career, and it would be nice if they know how to approach them and don't panic."

In addition to developing a taste for making sense of the world around them, the lecturer would like them to have the leave with a grasp of the mechanisms behind various physical phenomena, particularly those that support their future development as engineers.

4.2.1.3. What pedagogical and structural changes have you implemented in PHY 107 and why?

When the Lecturer took over PHY 107 "[m]uch of the course was memorization of formulas and then plug-and-chug on the exams, where much of the mathematics, I thought, was trivial linear algebra [and] arithmetic. I didn't think it was very taxing for the students and…I felt that more needed to be done with concepts…I also was hoping that I could get some of them to at least enjoy physics and not think of it as a chore."

Over the years the Lecturer has gone through a number of iterations attempting to alter the course in order to appropriately challenge the students and offer them more of an educational opportunity. The three elements of the course are the lecture, which the Lecturer personally implements, and the recitation (workshop) and lab, which TAs instruct under the guidance of the Lecturer.

Lectures are used in a typical fashion to introduce topics, develop concepts, highlight typical trouble areas, make connections to things that either the students care about or impact their future careers, and inform students of the general nature of science. In attempt to make the course more active "I do demonstrations, and I try to have discussions about the demonstrations." Some of these demonstrations draw on the research-based Interactive Lab Demonstrations (ILD) developed by Sokoloff & Thornton (2006). ILDs require students to make predictions, discuss those predictions with their neighbors, watch the demonstrations, which is measured in real-time, projecting the readings for the entire lecture hall to view, and then resolving inconsistencies.

One of the elements the Lecturer tries to address is the nature of science. "I…try to give them a feel for a scientific point of view. 'Don't always believe what you see. Think about it. Try to find some model.'…Scientists don't find truths. Scientists try to build models that help us predict what's likely to happen if we do certain things to our system of whatever. Engineers take that stuff and they utilize it to build things that have some application in the world to make life easier for us or to get something done." One of the major ways the Lecturer brings these ideas in is through the history of how science has developed and current events that demonstrate this process.

Recitations have been transformed from TAs standing at the chalkboard lecturing solutions to homework problems for one 50-minute block, and going over sample problems during the other 50-minute meeting. Due to the low-level of student involvement in having a TA solve problems at the board and familiarity with physics education research, the Lecturer has shifted toward students working in groups on conceptually-based tutorials. The TA's role has altered from "the authority" to a facilitator acting as a guide, going from group to group offering guidance through Socratic dialogue, but seldom "an answer." The tutorials currently in place have been designed to elicit particular areas of student struggle and help the students to resolve their inconsistencies through paper, pencil, and discussion. The Lecturer takes special care to cater these tutorials more toward SET's mathematical ability, for these tutorials were designed for algebra and calculus-based courses. [28]

Initially, the tutorials were only implemented here and there. To allow students to become more comfortable with the format and take them seriously, tutorials have since been fully implemented in all recitations, with students working on a new tutorial every recitation (workshop). In addition, tutorials now integrate fully within the course: homework and exam questions come from the tutorials. A major goal of implementing these tutorials is to develop communication skills, build a conceptual background, and get students to actively participate in making sense of physics.

PHY 107 labs, meanwhile, have remained more in a traditional vein, although PHY 108 has shifted more toward labs seeking understanding (for a look into the Lecturer's continuing deliberation on an appropriate lab format for PHY 107, see Appendix U). Although not entirely sold on one approach to lab over another, "I think that some of the labs that…are considered to be traditional labs are good at demonstrating mathematical techniques [like] straight line plotting…[Additionally] being engineers they're going to have to learn something about measurement…I'd like to have them take measurements and be aware of units. I'd like to have them see that when you multiply quantities together, the units balance and the numbers have to balance…[T]hese guys are supposed to be engineers, they're going to be building things. They can't forget about decimal points, and they can't forget about units, and there's a ton of stuff for them to remember. This to me, the laboratory is their practical experience of being engineers. That's one of the reasons I haven't gotten into modeling labs"[29]

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[28] The tutorials currently used have been adapted from *Tutorials in Introductory Physics* (McDermott et al, 2002) and modified tutorials based on *Tutorials in Introductory Physics* (Ambrose, 2002).

[29] Modeling is an approach to lab developed at Arizona State University for the Lecturer's digressions on why the Lecturer has not adopted them see Appendix S. For information on the Modeling Instruction go to http://modeling.asu.edu/index.html

Deciding what belongs in this physics course specifically for SET students has been a struggle for the Lecturer. He has worked with SET faculty; some have given feedback, while others have been receptive to interactions, but light on constructive criticism. The Lecturer has scanned through the SET majors' course schedule, attempting to piece together a curriculum more appropriate to the SET population. Despite these efforts, the Lecturer still has questions about the relevance of some concepts for this group.

4.2.2. Teaching Assistants

The comments of the TAs are similar to those of the Lecturer. The TAs spend more time than the Lecturer (or SET coordinators) working with students one-on-one.

4.2.2.1. How do you view the SET students?

The PHY 107 population is very practical. "These are students that are very happy to take things apart and put them together. They're a very hands-on oriented crowd. [Now] they may not be as sharp when it comes to book work and number crunching," but "100% of the students that come over here have the capability." TAs experienced problems arising from two areas: the intersection of their attitudes & the material presentation and their math skills.

"A lot of them don't understand why they have to take physics." Given the practicality of these students, "[s]ome want to be in the classroom, get their work done as quickly as possible, not have to process anything, and just leave…For the students that want to learn, they're more willing to answer questions that you ask when they're stuck on something, and they're more willing to use their mental abilities." "You can maintain their interest if you pose questions and things related more to ["motorcycles and sleds"] rather than your standard block on an inclined plane."

One of the difficulties with this group is that many of them *are* willing to work hard, "if they know what the payoff is. They're very paycheck oriented. [To them], the payoff is that they get an answer…and it's right." Their need for *the* answer can make helping them rather difficult at times. They seem to expect the answer to arrive in one or two steps, and if it does not happen they lose confidence or the desire to continue and throw up their arms in despair. Because of this lack of confidence or “laziness to think…They simply take and guess something as the answer,” hoping that somehow the problem will go away.

Stepping back into the worker frame, the TA perception is that this group of engineers, unlike the PHY 121 crowd, appreciates less formal authority boundaries. They ”like to know that you’re working along with them. They like to see their boss working with them.” Another TA described a similar feeling: “I’d always try to walk the fine line of teacher/peer…I think it helps them feel a little bit more comfortable.” “I don’t know I just feel like you have to be down to Earth with them.”

Attitudinal issues certainly appear important for the PHY 107 students, but the other area of concern to the TAs resides in their students’ struggles with mathematics. Regarding math concerns, the TAs confirm the topics mentioned by the Lecturer: reasoning across the equal sign, combining terms with different denominators, solving simultaneous equations, working with variables (symbols), and using trigonometry. The one major element that the TAs brought up, and is illustrated by the FMCE results in section 3.2.2, is their poor skill for analyzing graphs. “They don’t know what the slope means. I don’t think it’s lack of ability, I think it’s just lack of experience.”

4.2.2.2. What are the most critical elements SET students need from physics?

Because each TA had slightly different responses, they are described in sections, below. Note that TA #3 had the unique MPEX2 score, discussed earlier.

4.2.2.2.1. TA #1

“I think it’s a bit much to expect that students will retain a lot more depth of concepts and things…[but] they can start to develop a physical intuition about the world and the way things work.” For instance they should be able to draw a ”free-body diagram and relate it to Newton’s 2nd law,… an EET might take away some simple laws and models, like [from] the current labs,… [and] be able to ask themselves how plot data to make a linear relationship."

Second, they "could take away a different way of approaching problems. A different way of looking at problems that may come up. In a way, that they can step back and say, 'Let's look at this problem from all different angles and analyze it first before we just try and barrel through.'"

4.2.2.2.2. TA #2

"Most of the details might not be that important for the individual…If the person can do independent reasoning from a basic point to some advanced point. I guess that's the skill that the student should take from the course."

The goal is to "make them think in a way where you have a mathematical model and some physical phenomena…Students should understand the math…[and] have an intuition for what's going on. These courses are done for engineers so [that] when they get into real situations, that kind of practice will be important in order to solve any problem."

4.2.2.2.3. TA#3

"They're supposed to learn physics to help them with their particular engineering subjects [and] get a background for doing stuff later."

One other element is the problem solving. "[A]ctual experience in the real world is going to demand some creative thinking, creative problem solving…This particular ability to walk into a problem and solve it. Maybe without knowing exactly how you're going to solve it. And have the ability to work through a problem that maybe you aren't sure how to approach it at first, but you start to take different paths to try to solve it. I think it's a real valuable skill."

4.2.2.3. What seems to be working well in lab and recitation (workshop)?

4.2.2.3.1. Lab

Regarding the specific labs, “The current labs, those were good.”

As for the students, “they worked pretty well in lab. With any group of four, you’d have one who isn’t the most involved and you’d have one or two who were dominant, but I think that happens all the time. To counter that I would go around and tell people to take on certain roles, changing whatever it was they were doing before. Generally speaking I’d say in the lab, [the PHY 107 students] are pretty good. Occasionally, you’d have guys screwing around.”

4.2.2.3.2. Workshop

When the students can actually play with things, these students do best. “Because they can actually make a prediction; although some of them play around with it, figure it out, and then make the right prediction. A lot of them don’t realize that their predictions don’t really matter”(i.e. the ruler on the nail for angular acceleration, the optics activities finding the nail with one eye, etc.). With some direction, they will play along and actually make predictions.

Though the TAs agree on the value of getting the students to think independently and learn for themselves, one of the major problems for these students is breaking things down into manageable steps and organizing systems to make them easier to analyze. “The workshop is the most important thing for fixing that problem.” An important note to make is that though the students put up a strong initial front against tutorials and working independently, “as the course goes on they understand that [they won’t get direct answers] and they will have to do some work by themselves.

4.2.2.4. What concerns you about the lab and recitation format?

4.2.2.4.1. Lab

As it is, “A lot of [PHY 107 students] don’t get ready and don’t read [the lab handout] ahead of time.” However, even if they did read the labs, many of the instructions contain errors, which is problematic when the labs consist of a series of explicit instructions. “They’re pretty good at following directions as long as they’re clear directions.” “I can tell you sometimes I’ll read those labs and it’s kind of confusing. I don’t really know what their point is.” When the students come across such a sticking point “a lot of them don’t read into it much when they get to it: they just stop.”

“For PHY 107 the most common [student] complaint is that the labs are too long.” “[S]ome of the guys are really getting upset that they couldn’t finish it, [and] two hours isn’t a lot of time to [understand the lab].” “They were always fine with collecting data and doing the experiment, but when it comes to analyzing the data it was always an issue, but it’s that way in 121 as well…I think that more than anything it’s just inexperience dealing with data. They seem to separate equations from the book from what they’re doing in lab and the real world, and I think it’s just inexperience…You’ll find it a lot when it says graph this and get the slope and they don’t know what the slope means. [Again], I don’t think it’s lack of ability; I think it’s lack of experience.”

4.2.2.4.2. Workshop

“When you have five or six groups, some students get uncomfortable because you can’t really make it to everyone for long. Sometimes if you don’t give them more attention, they can’t proceed from one point to the next…, [as a result] most of the time they just waste time.” “Sometimes [when] they get stuck it’s because they are not willing to sit back and think in small steps, “ but sometimes they fail to see the question they are trying to answer. There appear to be holes in their ability to visualize or comprehend the scenario, which is problematic when all they have is paper and pencil and the single instructor making rounds. They seek some sort of concrete verification either from a physical thing or the instructor, but for many of the tutorials they receive neither.

"I think it's frustrating for the students because I think the student perceives it as us withholding information from them voluntarily. And in a way we are. They look at it as the teacher isn't telling them because they want to show that they're smarter or something like that…That's my guess. Because it can come across sounding condescending…I understand that the point is for them to figure it out for themselves."

The TAs major concerns regarding workshop were time, student frustration, and a feeling that the tutorials alone failed to offer the students full support. Their suggestions for improvement involved giving more time to complete a given tutorial— if the tutorials in their entirety and the process of students making sense of things for themselves are actually important. Second, Socratic dialogue may be the ideal and even has a place for these students, but for a group with such a low level of academic confidence, it may not *always* be appropriate. In conjunction with questioning, currently the TAs often end up giving the students the base elements of theory behind the tutorial in order to start the sense-making process. These students tend to arrive at workshop clueless as to where to begin or what they are even trying to make sense of.

For a group of students who appear mathematically and symbolically challenged, some of the TAs feel the tutorial is not the *only* answer. "In order to learn how to solve problems you have to solve problems…I don't think that students get enough from seeing the professor solve problems on the board all they do is they go through it and say, 'This is how it's done.' And it seems so easy. I think that if you have a TA do it, it's a smaller setting. A TA might be able to offer different insight into a problem…[However], the stance of [the Lecturer] took is that if they want help solving problems they should come to seek you during your office hours. Which is understandable, that's true, but you know as well as I do. You can have an office hour and have five visits over the course of an entire semester, maybe." The TAs see drastic issues in the homework and currently give little more feedback than notes on the student's work, even if the same problem, mathematical or otherwise, showed up in three-quarters of the class.

4.4. PHY 107 Student Interviews

Throughout the student interviews, all students placed heavy emphasis on how well things prepared them for preliminary exams, and determined the value of different aspects of the course and their study-habits based upon their inferred importance on those exams. See Appendix V to view tables comparing all interviewed student data and a breakdown of their MPEX2 clusters.

4.4.1. How did you study for this course?

4.4.1.1. Student #1: Low-math, High-physics

Table 22: Student #1 Data

	Major	Math-Context Bin[30]	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>[31]	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #1	CMT	low-high	40	49	55	0.12	61/26	42/39

"I take the homework pretty seriously…I think that's the best way to study is to do the homework and to understand it...[T]o study for the tests, I went back and did all the homework problems that we had and then would go and find homework problems like it in the chapter. So I pretty much just studied the homework for the tests…I don't get the best grades on the tests, but I don't fail them. So, I'm happy with it."

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[30] The class was split into high-mid-low bins based upon the math diagnostic *clusters* and high-mid-low based on a physics question. The category going across is read math diagnostic bin-physics question bin.
[31] The PHY 107 mean normalized gain here is the mean of individual student normalized gains, whereas the scoring template gives the normalized gain of the pre-/post- class means.

This student found that working alone, although the method familiar from high school, failed to suffice for PHY 107. "I tried for the first month of school to do my homework on my own and got terrible grades on my homework…It's not like I'm getting the answer off from someone because he doesn't have a clue what he's doing either, but the two of us can work through it together and get an answer, together….I think [learning to work in groups] is just something you have to figure out on your own."

"The book is really useful…I don't necessarily read the chapters when the reading assignments are given…,[but] when I do the homework, I more or less read the chapters because the problems that are in there really help….It has good examples and shows you how to work through the equations. It doesn't just give you the base equation and then what it moved the equation into. It shows how they moved through the equation…I'd like to see the TA do out the real problems…,but the book, I guess, is working good enough. It forces me to use the book."

"I would say that, quite honestly, I've taught myself most of [what I've learned in PHY 107.][32] At this point, the interviewer asked Student #1 if there is any value in having taught himself. "A lot of value to that because then it's more meaningful to you…It's more imbedded in your head if you taught yourself. In high school I forgot how to do stuff right after the test…I took AP physics…, but it was just completely done for us…, so I never really taught myself how to do any of it…But I think I could pass the first test from this year right now, if I were to take it. Because I taught myself how to do it, and so it's really in there good…I think that's what college is more or less like compared to high school…,but it's hard to get used to, and this course is what made me…study that way."

"My other courses aren't that hard, and don't require that much thinking or teaching myself. I haven't read the books in any of my other courses and I'm getting "A"s in them. So, I

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[32] Seemed mildly annoyed while he made this statement.

don't have to read the books, I guess. As far as passing the class, I don't know if I'm learning everything from the course, but I'm passing the class, [well] I'd like to get "A"s in all my courses."

4.4.1.2. Student #2: Mid-math, Mid-physics

Table 23: Student #2 Data

	Major	Math-Context Bin	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #2	EET	mid-mid	29	18	39	0.26	48/26	42/36

"I never took physics in high school. I took calculus and stuff like that, but physics is a different type of math…You can't just know the equation you've got to know for what reason and stuff like that. [In] calculus, I don't even know what the hell I'm doing, but I know how to maneuver my way around so I can get good grades in there."

"Before the tests, I'm in the library studying the whole day. I get the concepts, but when the test comes it's just the wording and I confuse myself. I'm not used to the wording. I hate it. Even through high school, word problems… I can do math…, but when the wording comes, you have to figure that out, puzzle it out or whatever…I think if you're used to word problems and stuff like that they get easier, but I'm not. I don't really like it. I just confuse myself."

After getting out some angst about physics and word problems, Student #2 began talking about differences between high school and college expectations. "It's not like high school because like high school you have like the whole year to learn one subject, but then this is half-semester. So, it kind of takes away the learning, and actually appreciating it and like learning it. Because you're just trying to get good grades and cramming it in…I can't say I hate physics, but I'd just say it's too much work."

With this statement the interviewer asked how Student #2 approached learning physics: "I think it's just like any other class in college, you teach yourself mostly. Because even after the teacher teaches, you have to go back to the…(trails off). It depends on what kind of a student you are probably…I mean like, [another student], he never reads the book. I read all the sections, that's the only way I can learn. He can just go to class and listen to the teacher and me, I have to read to understand to get the formulas and the why's this? Why's that? I have to actually read the book to understand what the teacher's talking about. So for me it's a lot more work."

Student #2 went on to describe the differences in actually learning versus making sure he gets the proper answers. "At the beginning of the school year we were working together like in a group and stuff, but that's crap. Because it was his style. He looks at the problem, looks at the pages and try to figure out the formula and figure out that way. But me, I figure that if I read the section first and then do the problems and try to do it that way, so it was a different style for me than him. Plus I went to like a teacher, not the tutors, I hate tutors."

"Tutor's give you homework to study… Last year, I tried a calculus tutor and it was basically a student, just like me, just got a good grade in it, whatever. And they tried to teach me basics or whatever, and I didn't have time for that. I was trying to learn this stuff, right now. They were like, 'Hey, work on this.' 'Naw. I have a test coming up. I have to work on this.' I never try these tutors. I hate them. But I go to a tutor [physics major or grad student]. He's real good, I like him. I do the homework first. Then on Tuesdays, I just go to him and say, 'Hey, what went wrong?' I switched over from doing it with [another student] and them because it just took more time…When I'm working on it,… if I can get it then I will do it, but I know that after working on it if I can't figure it out, I'm not going to get it. I know it. Even after reading the book. That's why I like the dude in [a dorm], he will show me how to do it and explain it to me. So then I have the answer right there, but then I know why…It's better than cramming, just looking at it for hours and hours. It's just a waste of time to me."

4.4.1.3. Student #3: Mid-math, High-physics

Table 24: Student #3 Data

	Major	Math-Context Bin	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #3	CMT	mid-high	45	15	18	0.04	55/29	68/10

Notable with student #3 is that the FMCE <*g*> was very low, while the MPEX2 scores were both above the class average *and* improved during the semester.

"[PHY 107] is kind of a big step from high school, where they kind of baby you and hold your hands…In lecture, it's not really on a personal basis, if you want to you can show up for lecture and take notes. And you've got to be really fast with taking the notes or you won't get all the material. But it's also hard to take notes on a new subject that you aren't really familiar with. Try to comprehend what's going on, maybe even think of, ask yourself a question or two, while trying to take notes at the same time. It's doing a lot of stuff at once. You almost have to go over your notes after class, but I don't think a lot of people do that…I know I didn't really do it too much. I did some on subjects that I wasn't really familiar with, but doing the homework though, helped out a lot. Just the overall change from the teaching style I guess is kind of a shocker at first."

"Lecture opened up the concept to you, then you had the opportunity in workshop to further it. And I think… if you did the homework that definitely gave you an advantage because you actually looked over the material that was covered. You had to use your book, look up formulas, write down problems, state the givens, state the unknowns, I think that that is definitely key to being somewhat successful in this course."

"Everything in high school was plug-and-chug: put it in, get an answer. Thank you…I found that you can kind of get away that way if you just knew how to manipulate the equations and everything, but you might not have the theory 100%, but if you know the variables and have a basic knowledge of the concept you could solve problems with givens."

At this point the interviewer asked Student #3 to clarify whether this course did any better at getting away from the plug-and-chug. "Definitely having to show your work. Definitely doing something, writing it, figuring it out in your mind, writing it down, and then having those there to look at kind of makes the work more concrete than getting it, typing it in to your calculator, and then getting a number…I guess that's pretty stressed on tests…If you get an answer wrong in one portion…it rolls over. The wrong answer rolls over because it's more about the process of getting *to* the right answer, not *getting* the right answer."

After some general comments about general interaction with the course, Student #3 discusses what led him to get a tutor. "At the beginning, I didn't really go over and look over the notes or look over the book or anything, didn't pre-read before lectures. And then before the first test, when I went to study I was kind of confused and that's why I went and got a tutor. Because I didn't really have any idea what I was talking about. But then I actually read my book and went over notes and that seemed to definitely bring concepts together. And then I tried to read the sections that we were going to go over before lecture and maybe if I did, the lectures made a lot more sense. So I didn't really have to go over my notes. When I was doing the homework, I would flip through the book and read some of the concepts and read some of the chapter review. And that definitely helped out in making the concepts more concrete." [33]

The interviewer then asked Student #3 whether most of his studying was alone or with other students. His response, "Well, we did have a couple of people in a group. But they felt that it wasn't doing anything for them so they dropped out. I did a lot of my work [during work-study], Monday, Tuesday, and Wednesday nights. Whenever I had questions I'd write them

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[33] When asked how his physics text compared to those of other courses, Student #3 said, "I don't know. I didn't really use a textbook at all this semester, other than in physics. We didn't have to in any other course. I bought 'em, but didn't use 'em."

down. I'd note what the problems were and ask either [my TA], [the Lecturer], or my tutor. And we'd pretty much go over them there."

Before the second exam, Student #3 corralled some other students to go over the practice preliminary exam. "I think that helped out a lot because even if I had the right answer, we went over how to do it again with someone else. And if someone else didn't have the right answer, I'd go up and explain the work that I had to them, and…we went over it again and made the ideas more concrete."

4.4.1.4. Student #4: High-math, Mid-physics

Table 25: Student #4 Data

	Major	Math-Context Bin	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #4	EET	high-mid	58	15	12	-0.04	32/42	22/55

In contrast to student #3, this student had far lower MPEX2 scores and a negative gain on the FMCE. Still, on the diagnostic, the student scored in the middle range on the math and in the high range on the physics context question.

"I thought that I was going to be able to do a lot better than I have done so far. I took physics class in high school…You know [, but] we didn't get into anything quite like this…I don't know. I'm not happy with my prelim grades."

To deliver clarity Student #4 was asked to explain what has been the difference. He started to explain, "[the] concepts are hard to grasp sometimes. And I think it's because I'm like a visual, like a literal kind of person. So I try to imagine [posed situations] in my mind, but I imagine it wrong. So I do it the wrong way, or I try to solve it the wrong way or something like that." Student #4 indicates the torque problem (Appendix J) as a prime example. "That angle [phi indicated in the given diagram] makes me want to think that the board is tilted, but in the picture it's level. So I just confuse myself. Like, I've always thought that normal force is opposite of gravity. Gravity's straight down, so why is the normal force going off at an angle?...[I'm] just trying to picture it in my head. And [I'm] imagining the wrong thing…, imagining [the situation], not the way it actually is, or something."

Attempting to further this subject of where his struggles on prelims were coming from, he says, "A lot of points when it was just mistakes, I was being stupid…If I had looked it over once or twice more, then I could have picked up on them. But then a lot of points [I] lose from not knowing what the hell I'm doing. Not knowing what the concept I'm suppose to apply to this problem or what equation I'm supposed to use for whatever I'm looking for…I just remember sitting there for the longest time pissed because I couldn't figure it out. So, just upset that I didn't know it."

"[Physics] has been a lot of work. So I obviously had to adjust to being able to manage getting everything done. [Other classes] aren't like, 11 o'clock. It'd better be here and it'd better be done, or else you're done…So that was a little bit of a change…I've learned that good grades aren't going to come very easily, like as easily as I've experienced or as easily as I'd expected. And so I think that I really have to prepare better…like studying more, studying better."

The interviewer asked how Student #4 studies. "I usually read some of the notes. I don't think I take very good notes. Like I just copy the stuff down that goes up on the projector, and then when I go back and read I don't even know what he was talking about. Because I wasn't listening to what he was saying… I don't dare just listen to what he says and not write anything down because then I'd be afraid that I forgot something. And I just wouldn't have any documentation of it at all. So then I'd be totally screwed. So, I don't know how to balance listening to him and getting everything that he says down. I just copy everything word for word… and that usually doesn't end up helping me that much."

"Sometimes I like to sit and read my notes by myself, but a lot of the time, I like to go and get with some guys and go over this stuff together. Because a lot of the times, they'll know something I don't and I might know something they don't, so that's…helpful. Sometimes they can explain it better to me than one of the teachers could."

When studying for prelims "I don't sit down and do a bunch of problems… I'll just read notes, try to memorize formulas, equations, and then just do the practice prelim. And because I don't do those problems I think is why I don't [review] the workshops[34] because that's all it is doing problems…I just don't go back and look at those because I don't want to do those problems." From reviewing as he does, Student #4 claims that it "just refreshes your memory…[It] makes it so you don't totally forget about it. Or like have it sink way back in there somewhere, so then you just can't even remember anything about it come test time…Looking at equations… helps you memorize some of the more important ones."

4.4.1.5. Student #5: Mid-math, Mid-physics

Table 26: Student #5 Data

	Major	Math-Context Bin	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #5	CMT	mid-mid	32	9	9	0.00	29/39	23/58

This student had very low FMCE scores, no measured gain, and very low expectations as measured by the MPEX2.

Student #5 is the only student where the interview felt tense, and he was also the only student relatively reluctant to freely share his thoughts. He did, however, have a small amount to say about how he went about studying for PHY 107. "I've been trying everything: study old tests, read the book, homework, work with friends, try to learn stuff better, practice prelim. You name it, everything…Well, I haven't really been doing too well on the tests, so…none of it's really been

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[34] He's referring to the tutorials from recitations (workshops).

panning out for me. But I think looking at the homework and doing the more difficult problems on the homework helps. And reading the book. And understanding the concepts in the book." At this point, he appeared to just be tossing out things, seemingly hoping the interview would quickly end, but he appeared to be at a loss in general, as well.

When asked what kinds of things give him the most trouble, he replied, "Trying to figure out which formulas to use for which equation, basically, that's where I get hung up. What information to use in the formulas. That's basically it."

To get a better perspective of what he thought would have helped him better prepare himself before entering the course, he said, "A little more better math skills. Just algebra skills…I think it's more just understanding the material and the formulas, basically…And knowing how to use the formulas that are given."

4.4.1.6. Student #6: Mid-math, low-physics

Table 27: Student #6 Data

	Major	Math-Context Bin	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE <*g*>	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19(s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #6	CMT	mid-low	40	6	9	0.03	48/22	13/42

Not only did this student start and end the semester with very low FMCE scores, but the student's expectations worsened considerably during the course of the semester. There seemed to be a strong mismatch between course goals and student performance.

Student #6 began like many of the others, comparing his PHY 107 experience with that of high school: "my high school class was really a joke compared to this…The difference? The teacher. The homework was pointless. He went over the homework in class, everyone just copied down the homework when he was doing it on the board. Then labs, you do any work, it's like you get credit for anything. I don't know. The high school class was not very helpful in preparing me, in all honesty. I don't know what else you could do to better prepare for this class…There weren't really too many big differences that I had to adjust to. Pretty much you just deal with the differences. I guess that's what everyone does, you kind of have to."

"We went much more in depth into each topic than compared to high school. High school we kind of skimmed over things and we didn't really go into detail. If we didn't really understand it, it's like 'Oh, you can talk to me after class.'…Going into depth on all these topics I guess was a little more difficult."

With regard to studying for this course, "Homework was helpful… After lecture you kind of apply your notes to the homework and then it's actually putting things together on your own. [To supplement the homework and study for the exams] reading the chapters over has become a good habit…I never did that in high school for physics…Something about rereading something helps me understand it more. Just seeing it again, I guess helps." Student #6 struggled to identify what if anything actually helped him and how it helped.

When asked more specifically about his exam preparations Student #6 discussed "rereading the chapters…skim over topics, look at notes, look over problems, doing the practice prelim…", but he placed most emphasis on reviewing steps from homework problems and working through the practice prelim. For the most part, Student #6 preferred to work in isolation, except "if you have questions on certain problems you go to someone else."

4.4.2. What was your impression of Recitation (Workshop)?[35]

4.4.2.1. Student #1

Student #1 (low-high, with FMCE $<g>=0.12$) stated, "The workshops that we do are helpful, [but] I usually end up going over them outside of workshop because I generally don't get much done during workshop for whatever reason. Because I'm with other people and it's a social

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[35] The author instructed over half of the students for recitation, and although blind to the identities of the students names when selecting students, all but Student #1 were students of the author.

hour…I don't think I learned very much in workshop. [I see it as] forced studying time, but we pretty much do it on our own…Once in a while we'll ask for help, but really, it's more beneficial to do it on your own….The workshops are helpful, and I refer back to them to study with because it's pretty much what helps you on the multiple-choice questions because they're more, just thinking about [the situation], not actually applying equations most of the time."

4.4.2.2. Student #2

Student #2 (mid-mid, with FMCE <*g*>=0.26) seemed to really be struggling to make sense out of the physics and appeared slightly frustrated that the attempt at sense-making further clouded the "correct" answer. "Like workshop. I mean it's good that [we] think on our own, at the same time, I don't know. Sometimes when I just can't get it, I just give up on it, especially with physics. You get your own personal what you think is going to happen, but then the book or the real reason. I mean it's true, but you don't see it. You're stuck to your biased belief or whatever it's supposed to be. Like with Newton laws, I would never say that third law always happens. It's impossible. Like in your head is thinking that way, I mean it's good that we think on our own, but at the same time."

"After a while as the year progressed, I did not expect anything from workshop. I'm just like, 'Aw, man.' I didn't even try, even from the beginning [of later workshops]. You know, I'd look at it. Then if I'd see something that I knew I was just going to confuse me even more. And like, you'd give us the equations and we'd think about it, that was good because then we could discuss it, but when we were stuck, stuck and nobody in the group could get it. That just gives up or whatever. Then you gotta wait until your turn comes, and a lot of time gets killed that way. I don't know how to improve on workshop, but that's the way I saw it."

4.4.2.3. Student #3

Student #3 (mid-high, FMCE <*g*>=0.04) began by discussing how difficult even starting workshop could sometimes be: "I think in workshops, if maybe [the TA] did a brief review of actually the concepts… [to] clarify the topic maybe a little bit. [You know] get a handle if you actually know the subject or if you don't know it and maybe get some answers of yes and no. Because if you're struggling, I know I tended, it's easy to get distracted, especially when you don't really know what you're doing. But if you have somewhat of an idea [of what's going on, then OK], but if you're completely lost, I didn't really find that a good way to introduce new material . Especially when you have a two- or three-page workshop assignment and you get the first few problems done and then you're stuck. Then you're stuck and then you don't really know where to go from there…It might help you out more than just getting a page done of them. You could get more into the theory [of it] deeper."

4.4.2.4. Student #4

Student #4 (high-mid, FMCE <*g*> = –0.04) did not explicitly discuss workshops on his own, but when asked about how they impacted his studying he replied, "Workshops never crossed my mind. I'll be honest. I never looked back at those. Not a single time. Not once. I put 'em in a folder. I still have them. Never looked at them. I don't know. Maybe I'm doing something totally wrong. Maybe I could benefit from looking at those, but I just never at look them because I wouldn't know. When I study, I don't sit down and do a bunch of problems. I just don't go back and look at those because I don't want to do those problems. And I don't think that I could just get anything out from just reading through the workshop." Student #4 seems to be in search of a bulleted list of efficient statements of fact and to avoid any possibility for having to let his own thoughts get in the way, remember that he "tries to imagine it in [his] mind, but [he] imagines it wrong so [he] does it wrong."

4.4.2.5. Student #5

Workshops were very frustrating for Student #5 (mid-mid, FMCE <*g*> = 0). He attempted to explain why: "Recitation. It would have been helpful if we had gotten more direct answers. Not as if we were just led out on a limb and then kind of just left to think about it ourselves…If we don't have the right answer, it's kind of hard to know if we are doing the right steps. If we don't' get direct answers telling us that we are doing the right steps, it's kind of hard to keep following those steps if we don't always get the right answer…A little bit more explanation would have been helpful.

"You have to get kids to think about what they're doing, but I mean there comes a point when they're just not going to understand it. They just don't get it, so you're going to have to help them through it. You just gotta tell them where to start…You can't just keep asking questions when they don't know the answer to the initial question...because you don't know if you were initially on the right track…I mean if you didn't understand it to begin with or you thought you understood it, but you were wrong, it's going to hurt you in the long run. I mean, that's where I was a lot in this course. I initially didn't understand it and didn't really get a lot of the answers I needed,…so it hurt me in the long run." These last comments seem to reflect the idea of one of the TAs: Student #5 felt like the instructors were not only withholding "the answers" from him, but punishing him on exams for not arriving at "the answer."

Student #5's description of workshop is interesting considering his struggles. "Recitation helps to understand the basic concepts of it, but when it came down to it, a lot of the basic concepts were easier and the difficult aspects of the course were in the math and using the equations to solve for stuff.…[T]he equations and stuff, I didn't even have a grasp of."

4.4.2.6. Student #6

Student #6 (mid-low, FMCE $<g>$ = 0.03) found the amount of tutorial remaining at the end of workshop rather discouraging. "The workshops that we did were sometimes like three pages and we only did a couple problems. I felt like we could have benefited more from those. I don't feel like I got too much out of the workshops. I mean I got some things, but not too much helped me from the workshops. [What would have helped would be] spending more time completing more of the problems. Because didn't [the Lecturer] say that a lot of the problems [on the exam] come from workshop? …We [onlyl complete like four [questions] and [then] we don't look at them again. And we don't really have time to finish the workshop on our own. [I mean] you're working on explaining problems and thinking through them and what our thought processes were. And the ones that we did do, [the TA] was helpful with those, it was just there was so many more…"

4.4.3. What was your impression of Lab?

Only those students who discussed lab specifically appear in this section.

4.4.3.1. Student #2

"Lab was a different type of physics. It wasn't even like the book physics. We used different equations [and] we used different names for figuring this and that…Cause we had to do it I think…I don't know exactly which one it was, but I mean some were on point, but some were (trails off)." These statements may reflect Student #2 considering physics as unrelated to the real world as measured by his MPEX2 reality cluster.

Student #2 reflects some of the SET Coordinator concerns about processing the lab. "Plus the lab. You were just trying to get it done…I wasn't really thinking…Some of the labs I didn't even worry about the concept it was, just didn't see what it was. If I'd try, probably I'd see what it was, so that the lab is probably my fault…[But the lab where] momentum was concerned, it was really close, I mean with experimental errors…I did get something out of it. It *proved* it, instead of just believing it."

4.4.3.2. Student #5

"I think that labs helped out a little bit [to] understand the material better because it would actually give you a hands on application of it and showed you in real life. That's how I learn a lot better than doing book stuff." Seeing the event gives Student #5 some of the concrete "answer" he so desperately desires.

4.4.3.3. Student #6

Student #6 reiterates some of the SET Coordinator concerns about lab. "Labs were somewhat, kind of helpful [,but] I felt like sometimes we were just trying to get things on paper instead of actually understanding the actual concept…Sometimes the labs weren't as helpful as I'd hoped they were [going] to be. I felt like we were just going for the grade instead of actually understanding what the hell was going on with that thing…more focus on getting it done and doing it right. Sometimes, one person of the four understood what was going on and [the other] people just followed."

4.4.4. What alterations to the course structure do you think would be helpful?

4.4.4.1. Student #1

Student #1 had two comments: one regarding the use of interactive lectures and another about more feedback regarding homework. "The couple of classes [the Lecturer] did the interactive lecture, that really helped. Those topics I really understood well. Just from having to sit there in class and write something out while he was doing something on the board. It just made you apply the theories and equations he was giving you rather than just knowing them, seeing them. Because you can't…know them unless you apply them. You can see it on paper, but it doesn't make any sense until you do something with it. At least for me…I thought that worked really well. And I know classmates did too."

With regard to workshops, "I'd like to have the old homeworks gone over… It would be really useful to, after you've already done the homework…Kids aren't going to pay attention if the TA's just doing a problem out of the blue. Whereas, if I've worked through the homework, got frustrated with this problem, spent an hour trying to figure it, and then I see him go over it after I've figured it out in my head or didn't figure it out in my head. It would either show me how to do it or make something click when he was doing it. Even the example problems that are in the book, sometimes it's hard for me to follow them. Usually they're pretty good, but to see someone actually talking through them would be helpful. And actually not just saying, here's the problem, this is the equation that you would use, but actually putting the numbers into it. Cause sometimes, with all the alpha and theta and seeing all of the different things and whether sine or cosine, sometimes it's confusing to see, 'Oh, here's the equation that you come up with.' Because you have so many different numbers that you're given that it's hard to know how to apply them unless you see someone else do it. How to take them from how they're worded into the equation that you were given…If I get them wrong on the homework, I still don't know how to do them when I go to the test because I put in the effort when I tried to do the homework and still never got showed how to do it right. I mean there might be a couple of notes, like 'Use the work-energy theorem' but that doesn't mean anything to me unless I see someone work it through."

4.4.4.2. Student #2

Student #2's suggestions revolved around giving more time for exams[36] and a restructuring of recitation. "The test is fifty minutes, [so] I try to rush things." He says more time will help him. "If I had a lot of time, I'd do better…Some people do it fast and get done early, but, me, I'm always the last person in class. And in all of my other classes, they're like two hours or a longer time than fifty minutes, but when you're trying to crunch things…you kinda overlook the little things."

For recitation, as a result of his failed attempts at sense-making of his thoughts with the physics ideas, and not getting the more immediate feedback from the TA that his group needed, he suggested large teacher-led activities to avoid confusion and down time. "Let one of them be a class probably and the other one be a group discussion. Cause, alright, we get that in lecture, but, ok, if we discussed in as a class too, that would be even better. I think we'd get more stuff done that way, too, because when you go group by group, its easy to stay off task…I mean it's good for

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[36] English is Student #2's second language and he likely could have sought help to meet this time concern.

us to think on our own, but, I don't know, throughout the year, I don't even think I tried that much in workshop. I just gave up on it, 'Not another day in workshop.'

4.4.4.3. Student #3

Student #3's suggestions included: some more attention on problems requiring synthesis of ideas and some slight modifications to the start of workshop (see section 4.4.2.3 for details). Overall, Student #3 had little complaint: "I think that everything's there. It's just a matter of if you want to go and use all the resources. Such as office hours,… you have to put in the extra effort, I guess, and a lot of kids don't really, don't think that it's necessary. It's definitely, all the resources are there. It's just a matter of if you actually want to be motivated to go use them. That's what I believe."

The element regarding synthesis stemmed from Student #3's frustration with the torque problem (Appendix J). He was not alone in his frustration. This problem bothered all six of the students interviewed, and this interview was their third encounter with it. Student #3 attempted to explain the frustration, which echoed with all students except student #5. "I know that question, I've seen it before and I still can't do it. That was a test question. It's all simple. Well I shouldn't say simple concepts, but it's all concepts that we've learned and it all needs to be brought together in one, to find, to sum the torques, and I don't think there's enough emphasis on. It's not finding it in the x-direction of one, there's multiple components that you need to be able to realize what they mean and put them into one formula. I guess that you're deriving. And I just don't think that there's enough time spent on that. We spend it more individually."

4.4.4.4. Student #4

Student #4 had very little to complain about, but if he had to gripe it would be on the homework feedback. "I don't know if I ever felt [like the course wasn't offering me something that I needed]. Like I wasn't getting enough help or something like that…[But,] sometimes I'd get my homework ["or a test"] back, and it would say, 'No, you're doing this wrong,'[well, "not literally."] And then it would have an equation written out. And so I'd be like, 'OK.' And I wouldn't know exactly what I did wrong. So like if someone actually told me why I did this problem wrong. Or what I did to get that wrong. And then how to do it correctly. And I think I probably would have been able to benefit from that."

4.4.4.5. Student #5

Student #5 really wanted some "direct answers." As such, he had some thoughts on the content in recitation.[37] "I think if the recitation had more math and not so much of the basic understandings, it would have helped me out." The focus of Student #5's discussion, always came back to manipulating formulas and having "the answer."

4.4.4.6. Student #6

Student #6 had three concerns: homework review, the lead-time of the practice preliminary exam, and time given for a single tutorial (discussed in section 4.4.2.6). He would like reviewing homework in workshop "because you were doing problems on your own and with other students and you see exactly what you did wrong so you can learn from it." The other element concerning student #6 is the practice preliminary. "It would have been helpful to have the practice prelim earlier so that we could go over different problems more with other students or people in your dorm…I don't know if it's too much asking for the practice prelim the previous week instead of the week of." Despite his brief requests he says, "Not too many major things come to mind. I mean, it was a pretty straight forward class. Help was there if you needed it."

4.4.5. What do you think is the importance of a physics course?

There was a strong disconnect between what physics instructors see as the role of a physics class and what the students perceive it to be. Or, if students state goals consistent with

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[37] See section 4.4.2.5 for more details from student #5 regarding recitation.

those of the instructors, there was enough detail to show that the students were not clear on how to meet these goals.

4.4.5.1. Student #1

“I don’t know why I’m taking physics. Only because it’s on my course registration thing, that’s just one of the courses required. I don’t see how it’s going to be useful in taking building construction next semester…I guess it makes you think more…Most of the stuff, in my opinion, you don’t have to look at it as a physics standpoint. You can just see that if you put a bar on a wrench, you’ll be able to loosen the bolt easier…but I don’t need to know why, I don’t think. In my opinion, it’s not going to help me much…

The study tools from how to work through problems that look ridiculous, I think that’ll be applied in my other course, but not the actual material…The study tools, it’s definitely a ‘teach you how to take a college course’ in my opinion.”

4.4.5.2. Student #2

“I’m in engineering, so [physics] has to be important because problem solving and all that stuff…I already know it’s important, but for me there’s too much in my brain. I let them figure it out and then tell me. I won’t figure it out.” Student #2 touted the physicist’s stereotype of an engineer., that an engineer just wants the information and cares less than they should about the how or why. But he says, “I understand more about things. ‘Cause it gave me experience. So I look at it differently… because [before] I would just use common sense.” Student #2 seemed to have decided that his thoughts should not be reconciled with physics, which is reflected in his pre- and post-instruction 0% favorability in the MPEX2 reality link cluster.

4.4.5.3. Student #3

“[In construction project management] if someone’s explaining something to you, you need to know what they’re talking about. You may not necessarily know how to get to that, but you need to understand the concepts. And what they're saying. And what a Newton is. And what a force is in the y-direction. When they tell you… you need to know what it actually is and be able to follow along and have a good sense of what they're talking about, I guess.

[Aside from professional work] you might be able to just predict the way something might act…You just do a lot of things naturally because you know the way the results are going to turn out, and this just goes a little more in-depth to why it actually does what it does."

4.4.5.4. Student #4

"I think that it's good to know this stuff. Like all the different concepts because, like I don't know if I'm ever going to use this stuff again, but, personally, I like to know. I like to *know* that stuff."

4.4.5.5. Student #5

"I think I've understood some of the more basic things of stuff that you see in everyday life, and explains why that happens and what's going to happen if something happens. You know what I mean?"

With regard to tools for thinking or learning: "It's been a real challenging course for me. And other than that I haven't really gotten a whole lot from it."

4.4.5.6. Student #6

"I guess in the field like engineering, like most of us are in, I guess it's going to help us with our careers, but I don't know. Some of the concepts, it's like, why are we going to use this in our life?… [But] I pretty much have a decent understanding of most of the concepts. There are some that are pretty fuzzy… After this, I pretty much have a good basis of what physics is about, or partly what it's about."

Chapter 5: Discussion

5.1. Overview

In this section, we discuss trends observed from the data described in Chapter 3 and explored in more detail in the interviews summarized in Chapter 4.

5.1.1. PHY 107 Instructors vs. SET Program Director & Coordinators

5.1.1.1. Perception of their students

5.1.1.1.1. Student characteristics useful for instruction

The SET Program Director & Coordinators and the PHY 107 Instructors see the characteristics of these students in a very similar light. First, and foremost, when these students arrive to UMaine, they are a "hands-on" group and require kinesthetic manipulation of objects to help them visualize a given situation. Strongly linked to this kinesthetic learning is the students' need to see/get results; they seek feedback to develop further understanding. The second perception is that when their students perceive value in course material or have their curiosity piqued, they are very hard workers. To help them perceive the value of the material, the instructors/course needs to make sure students know why they are doing what they are doing; they are a very pragmatic group. Despite this pragmatism, and unlike the typical engineering crowd, these students are said to respond very well to instructors demonstrating personal interest in them and breaking the status barrier between instructor and student.

The student data gathered in this study and presented in Chapter 3 do not necessarily support the perceptions by the SET administrators and PHY 107 Instructors. Student learning of important physics concepts (as measured by the FMCE) are strongly connected to MPEX2 scores on the coherence and conceptual clusters. The coherence cluster includes a "real world" component, consistent with the relation between course material and a "pay-off" for learning it.

But, the relation between the concepts cluster and FMCE gains shows that those students who seek more than hands-on, pragmatic results are more likely to succeed, as well. Also, the data show no correlation between mathematics skills (strong or weak) and normalized gains on the FMCE.

5.1.1.1.2. Barriers for instruction

The major difference between the PHY 107 Instructors and the SET Director & Coordinators view of barriers to instruction was their attitude toward those barriers. The PHY 107 instructors appeared less accepting of the students' weaknesses; the SET demonstrated a certain amount of pragmatism, essentially saying, "these *are* the students we work with." Though their levels of acceptance of what they see differs, they seem to agree to a great extent with regard to the struggles faced for instruction.

The most difficult battle for all is the students' desire to "get-by." The majority of these students come to school to get a high-paying job rather than to get a general education and as such, getting them to see value in anything fundamental meets opposition. Their pragmatic nature seeks to put forth little effort for things they see little value in. This attitude of theirs spreads to the low value they place on study skills, verbal communication of thoughts and processes, attempting to reflect & think in small steps, and the physics course itself. In addition, these students have limited experience with studying in high school, thereby creating holes in the skill sets with which they enter the SET program, which includes the math concerns that all perceive. Unfortunately, because of the students' pragmatism and *very* strong notions of what *is* important, anything that differs from their expectations faces rigid resistance. Due to student resistance mixing with student inexperience and spotty academic background, these students may require more time on task to make sense of material than a more academically inclined group, seeking to only give the instructor what they want to hear.

5.1.1.2. Expectations for student development in an introductory physics course

According to the MPEX2 results for the PHY 107 Instructors and the SET Coordinators, the PHY 107 Instructors align well with the MPEX2 experts, whereas the SET Coordinators appear much more indifferent as to whether students should try to assimilate the material in a physics course and try to make sense of the underlying ideas. The interviews, however, revealed a more complete picture.

As mentioned in their views of the students, the SET Coordinators appear to accept that their students enter with a certain attitude; and although they would like an immense amount of immediate growth, they recognize that the development will take the entire undergraduate program. In addition, the range of disciplines in PHY 107 causes many of the specific concepts to have a primary function of preparation for the Fundamentals of Engineering Exam, rather than actual discipline development, and helps to give the SET students a more rounded education. As such, the measured neutrality of the SET coordinators in the concepts and coherence clusters of the MPEX2 appears to be a combination of the relevance to their discipline and the SET Coordinators' realistic expectations for their students rather than their ideal, which they see as unattainable.

Because all of SET's general goals for introductory physics align well with the PHY 107 instructors, I will focus this discussion around their objectives.[38] Though the SET appreciates concept development and fosters developing a physical intuition, the SET leaders focused more on process development during our discussions. Of particular interest to SET is developing students':

- ability, and inclination, to predict, rather than to "just do it"
- ability to translate words to mathematic symbols and mathematic symbols to words

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[38] I will not discuss credentialing specifically here, because aside from particular topics on the Fundamentals of Engineering Exam, the credentialing refers to ABET standards, which align with the SET Coordinators goals.

- level of achievement to a standard-level, fully aware that a small percentage will fail and another small percentage will greatly exceed the standard
- understanding of why they are doing a certain lab or activity
- ability to trouble-shoot problems as they arise
- ability to understand what it means to have data that supports a conclusion[39]
- ability to explain their answers verbally

5.1.2. PHY 107 Students

5.1.2.1. Skill sets and indicators compared with more typical introductory physics populations

The SET students appear to be average students at the University of Maine according to the indicators, but with respect to those of a rigorous science or engineering program, SET students arrive needing to develop much more within their undergraduate program.

Looking first at the University of Maine, we can see that the SET's mean SAT scores for a group completing a semester of physics (1050) align well with the mean of the UMaine population (1080). The SET students' scores are far below the 1260 range of their typical engineering counterparts.

The majority of SET students come from the top 20-40% of their respective graduating high school classes. This high school ranking places them in the top 40-80% of all students coming to the UMaine. Meanwhile, the entire College of Engineering, which includes the School of Engineering Technology, has 60% of their students coming from the top 20% of their graduating high school class with only about 30% of their students ranking in their high school's top 20-40% (The UMaine Office of Institutional Studies, 2006).

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[39] If using data is actually important to come to conclusions, then these pragmatic students will avoid using the actual data if their grade is determined on the correctness of their data, rather than using the data correctly to draw an appropriate conclusion.

Math skills were a primary concern for PHY 107 instructors and recognized by all the SET leaders. Using the Math Diagnostic in this study to compare the PHY 107 population with a more typical algebra-based introductory physics population, we see that their mean (47%) level of math skill places the majority of PHY 107 students in the bottom quartile of the comparison population. Furthermore, 68% of the PHY 107 students fall into the category of having an 82% chance of scoring a C- or lower in the comparison course.

5.1.2.2. Beliefs about appropriate methods for learning in an introductory physics course

Using the MPEX2 to inform us of differences between the PHY 107 population attitudes toward learning physics and more typical introductory physics populations, we believe that the PHY 107 students are less inclined to expect to have to understand concepts in order to utilize equations and connect equations to the physical situation they are confronted with. This increased expectation to succeed without understanding the problem at hand with a low level of facility with the required math skills very likely places the SET students at a disadvantage when they attempt to solve problems.

PHY 107 students say that they have had little practice studying, meaning thinking for themselves and being held accountable for knowing what they are doing in an academic setting. Even in college, they will only study if they have to in order to get by. All students interviewed felt they had to study for physics, but their inexperience with studying leaves many of these students with little idea of what kind of studying will most help them succeed in PHY 107. All of the students placed a high value on the homework and understanding how to do the homework as a means for studying for the exam. If material or methods were not reflected in the homework, they found them of little use. In addition, with half of those interviewed feeling like they did not have time to actually make sense of the material, they opted to focus their efforts more on the "right answers". Anything that might confuse them or fail to help them acquire the accepted right answer had little value; these students expect that come test time they will be held accountable for having the correct answer.

Furthermore, students who focused on visual representations struggled if left *only* to their own thoughts because they failed to resolve why their initial mental image was insufficient after their work was marked incorrect on their homework or exam. They struggle to find another perspective in order to make sense of the situation. For students that have no idea of where to begin a problem (generalizing from the MPEX2), let alone finish translating a situation to solve a problem (generalizing from the Math Diagnostic), students require some method for additional feedback.

Many students complained about the amount of time the instructors actually spent helping them figure out how to even begin analyzing a problem, and student inability to finish what they were given in lab and recitation, never mind making any sense out of the material covered. They would like to have more help understanding how to make sense of the material in class through more direct instruction helping them understand the process. For instance, the PHY 107 would like to have: a TA review some of the problematic homework or errors that arose from homework, more of what the Lecturer referred to as “Interactive Lectures,” more time allowed to develop an understanding, and more hands-on, rather than paper-and-pencil activities, which would actually provide an additional form of feedback.

5.1.2.3. Effectiveness of current instructional methods for conceptual and attitudinal development

If a major goal of PHY 107 is to develop some primary concepts and more appropriate processes of studying and approaching problems, then PHY 107 is currently only moderately successful based upon this study’s conceptual (FMCE) and attitudinal (MPEX2) survey data.

The FMCE results for the PHY 107 course resemble results of a traditionally taught lecture course with the normalized gain of the overall survey around 12%. This score indicates that of the total number of questions that students answered incorrectly on the pretest, the students correctly answered 12% post-instruction. More typical results for a research-based lecture course fall in the 30-40% range.

The data also show that for this group of students, pre-instruction scores and normalized gains had a correlation coefficient of 0.38. Math skill, contrary to SET coordinator and PHY instructor assumptions, had no statistically significant correlation with development as measured by the FMCE normalized gains. The only indicator correlating better with the normalized gains of students than the pre-instructional FMCE scores were the favorableMPEX2 coherence and concept clusters (R = 0.52).[40] In addition, post-instruction favorable MPEX2 coherence and concept clusters correlated as well as the pre-FMCE normalized gains (R = 0.38).

These correlations suggest two things. First, the PHY 107 students starting the course understanding more connections between motion and force seem to build a greater proportion of the connections absent before instruction than those entering the course with fewer correct connections between motion and force. Second, students who either enter or leave physics with more favorable MPEX2 coherence and concept clusters tend to construct an equal or greater proportion of the absent connections following instruction relative to those students with higher pre-instructional FMCE scores. This finding suggests that students with favorable attitudes toward assimilating ideas in physics and stressing the use of guiding principles (concepts) when trying to make sense of a situation are more likely to develop a better physical intuition. These findings are rather encouraging, considering these two measures are the factors that the FMCE was designed to measure.

The PHY 107 class began on the low end of normal on the MPEX2, with students answering as constructivist physics experts desire only 46% of the time, 10% lower than other algebra-based lecture courses. In addition to having fewer favorable, the PHY 107 students began

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[40] Unfavorable scores had much less of an effect on FMCE normalized gains than favorable answers.

with more unfavorable responses, again showing a 10% difference from the comparison courses. These scores illustrate the PHY 107 population's greater expectation that learning physics should require little from themselves, but a great deal from the instructors. Over the course of instruction, as is typical with a physics lecture course, regardless of whether research-based curriculum is supplemented or not, students' attitudes become less favorable and more unfavorable. The only data from this study that served as an indicator for MPEX2 scores were FMCE scores and SAT verbal scores.

Prior to instruction the FMCE scores and the SAT verbal scores have a large effect size ($R^2>0.14$) on MPEX2 scores; however, after instruction only the FMCE scores are statistically significant in explaining the PHY 107 students' MPEX2 scores, and they decrease to only explain a moderate level of the variance in scores ($0.06\leq R^2\leq 0.14$). These findings suggest two things. First, prior to instruction students' verbal skills may play a large role in student responses to the MPEX2, but over the semester as the students become acculturated to the academic setting, SAT verbal scores fail to explain variance in MPEX2 scores. Second, students' conceptual development, as measured by the FMCE, explains a large amount of the variance in attitudes prior to instruction, but after instruction, students with higher conceptual development are less likely to have more favorable attitudes than they were prior to instruction ($0.06\leq R^2\leq 0.14$).

5.2. Limitations of this study

- This study only has data from a single year and may not fully represent the typical SET student population. However, the alignment with how PHY 107 instructors and the SET leaders described their students, and how the selection of students describe themselves through MPEX2 data and interviews, suggests that this population may be fairly typical of a group of incoming SET students.

- Due to this evaluation only investigating the current PHY 107 course, this study cannot prescribe curriculum change. This study can only suggest criteria for future studies and beginning the iterative process of further curriculum development for PHY 107.
- Though, when selecting interviewees, care was taken to include all SET majors, while representing the typical students as measured by the data, CMT majors represent the majority of those interviewed (4 of 6 students). The percentages of each major in this study's population were: 44% MET, 24% CMT, 18% EET, and 13% SVT. However, if the students' indicators are more important than their declared major, then those interviewed serve to represent the typical SET student.
- The pragmatic nature of these students may have led to students performing below their level of understanding because they knew performing poorly would not affect their grade. Student #3 supports this concern, "I know I messed up like the acceleration of like the velocity/time ones. I was getting confused and then I was just getting mad and wanted to get out of there. So. I was just thinking about it. I know I messed those up, but oh well. I pretty much knew. I knew pretty much a good portion of it, but it's just time. Who wants to sit there and do 3 bubble sheets of that on the last day of class? And then, you just want to get out of there, so you don't really, might not put in as much effort as you would if it was more of a test or something like that. That's the way I feel about it and I have a pretty good idea that that's the way a lot of other people feel about it too. But I guess there's only so much you can do about that, at this time. This time of the year, I guess. Because… it's Thursday. Tomorrow's the last day of classes before finals. You're either going all out or you're done. I'm done. I was done pretty much last week."
- This study's focus on big picture questions of understanding and student ability to process information prior to calculations has neglected to determine the PHY 107 population's calculative development. Thus, in order to make claims about numerical problem solving another study focusing on those characteristics will be required.

REFERENCES

ABET Technology Accreditation Commision. (2006) Criteria for Accrediting Engineering Technology Programs. Baltimore, Maryland. ABET, Inc. Retrieved on July 7, 2007 from the ABET Website: http://www.abet.org/forms.shtml

Ambrose, B. (2002) Algebra-based tutorials based on *Tutorials in Introductory Physics*. Unpublished.

Aron, A. & Aron, E. (2003) Statistics for Psychology. Upper Saddle River, New Jersey. Prentice Hall.

Breen, C.V. & Wittmann, M.C. (2001) Continuing Evaluation of Secondary Implementation of RealTime Physics and Interactive Lecture Demonstrations. Unpublished. Retreived July 13, 2007 from the University of Maine, Physics Education Research Laboratory Website: http://perlnet.maine.edu/research/rtpandild.htm

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

Crawley, H. B. (2002) M1 from the lab manual: The Math Diagnostic. Retrieved June 18, 2007 from the Iowa State University Physics 111 Laboratory Website: http://www.public.iastate.edu/~crawley/111/p111.html

Cummings, K., Marx, J., Thornton, R., & Kuhl, D. (1999) Evaluating innovation in studio physics. . Physics Education Research American Journal of Physics Supplement, **67** (7), S38-S44.

Description of Engineering and Engineering Technology Jobs. (n.d.) Retrieved June 5, 2007 from the University of Maine, School of Engineering Technology Website: http://www.umaine.edu/set/Whatis/index.htm

Donald, J. G. (2002) Learning to Think: Disciplinary Perspectives. San Francisco. Jossey-Bass: A Wiley Company.

Dykstra, D. I. (2002) Why Teach Kinematics? An Examination of the Teaching of Kinematics and Force— I. Unpublished. Retrieved on June 27, 2007 from Boise State University, Dewey Dykstra's website: http://www.idbsu.edu/physics/dykstra/Dyks.html

Elby, A. (2003) Template for the Analysis of MPEX2. Unpublished.

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

Hestenes, D. & Halloun, I. (1995) Interpreting the Force Conceptual Inventory: A Response to March 1995 Critique by Huffman and Heller. The Physics Teacher. **33**, 502-506.

Hudson, H. Thomas. (1986) Mathematics Review Workbook for College Physics. Boston, MA. Little, Brown and Company

Huffman, D. & Heller, P. (1995) What Does the Force Concept Inventory Actually Measure? The Physics Teacher. **33**, 138-143.

Important Information About the Placement Exam. (n.d.) Retrieved July 11, 2006 from the University of Maine, Math Placement Test Website: https://www.umaine.edu/mathtest/taketest.asp

Mazur. E. (1997) Peer Instruction. Upper Saddle River, NJ. Prentice Hall

McDermott, L. C., Shaffer, P.S, & PERG. (2002) Tutorials in Introductory Physics. Upper Saddle River, NJ. Prentice Hall.

Meltzer, D. E. (2002) The relationship between mathematics preparation and conceptual learning gains in physics: A possible "hidden variable" in diagnostic pretest scores. American Journal of Physics, **70** (12), 1259-1268.

National Council of Examiners for Engineering and Surveying (NCEES). (2005) FE & FS Exam specifications. Retrieved July 17, 2007 from the NCEES website: http://www.ncees.org/exams/fundamentals/

Office of Student Records. (February, 2007) Enrollment Statistics Spreadsheet. Unpublished.

The R Foundation for Statistical Computing (2007) R version 2.5.0. Retrieved May 14, 2007 from the R Foundation website: http://www.r-project.org/

Redish, E.F., Saul, J.M., & Steinberg, R.N. (1998) Student Expectations in Introductory Physics. American Journal of Physics, **66** (4), 338-352.

Saul, J.M. & Redish, E.F. (1998) Final Evaluation for FIPSE Grant #P116P50026: Evalulation of the Workshop Physics Dissemination Project. Unpublished. Retrieved on October 30, 2006, from the University of Central Florida, UCF Physics Education Group Website: http://www.physics.ucf.edu/%7Esaul/articles/index.html

Saul, J. M. (1998) Beyond Problem Solving: Evaluating Introductory Physics Courses Through the Hidden Curriculum. (Doctoral Dissertation, U. of Maryland, 1998). Retrieved on June 20, 2007,from the University of Maryland, U. of Maryland Physics Education Research Group Website: http://www.physics.umd.edu/perg/dissertations/

Sokoloff, D.R. & Thornton, R.K. (2006) Interactive Lecture Demonstrations. New York. John Wiley & Sons.

Thornton, R.K. & Sokoloff, D.R. (1998) Assessing Student Learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. American Journal of Physics, **66** (3), 212-224.

The UMaine Office of Institutional Studies. (2006) Admissions : Mean SAT Scores & Class Rank. Retrieved July 8, 2007, from the University of Maine, Office of Institutional Studies Website: http://www.umaine.edu/ois/fact_book/Admissions/admissions.htm

UMaine Mean SAT Scores for Incoming Classes. (n.d) Retrieved June 19, 2007, from the University of Maine, Office of Institutional Studies Website: http://www.umaine.edu/ois/fact_book/Admissions/admissions.htm

University of Maryland Physics Education Research Group (UMPERG). (2002) Maryland Physics Expectations Survey 2: version 1.3. Unpublished.

Wittmann, M. C. (2002) On the dissemination of proven curriculum materials: RealTime Physics and Interactive Lecture Demonstrations. Retrieved October 30, 2006 from the University of Maine, Physics Education Research Laboratory Website: http://perlnet.umaine.edu/research/mcw.htm

Wittmann, M. C. (2001) Template for the Analysis of the FMCE. Retrieved August 20, 2006 from the University of Maine, Physics Education Research Laboratory Website: http://perlnet.umaine.edu/materials/index.html

APPENDICES

Appendix A: Informed Consent for Interview

Project: To identify students' ability to access mathematics within an introductory physics course

PI: Daniel A. Reed, Master of Science in Teaching Candidate
Advisor: Michael C. Wittmann, Dept. of Physics and Astronomy

You are invited to participate in a research project being conducted by the Physics Education Research Laboratory at the University of Maine. The goal of this project is to help us understand how students learn physics, so that we can improve the instruction of physics in subsequent years. Your participation will assist us in this task, and we appreciate you giving your time to help us.

What we will ask you to do.

If you decide to participate, you will be asked to answer simple questions about physics and your expectations of how students interact with physics and related mathematics. For example, we'll ask you to describe what skills and abilities you would like a student to leave an introductory physics course with.

Risks

There are no foreseeable risks in participating.

Benefits

We hope that the information you provide us with will help us to better understand the intent and execution of the Technical Physics course. In addition, we hope to develop a stronger understanding of the SET students' background and future. We believe that your perspective will be of great benefit to future physics students.

Confidentiality

Your name will not be used in any public forum by researchers, and you will be referred to (if at all) only by an alias. Data will be kept locked in an investigator's office. Only researchers in the Physics Education Research Laboratory (and their collaborators on this project) will have access to the data. We plan to keep the data indefinitely, but never to use it without full confidentiality.

Voluntary

Participation is voluntary. If you choose to take part, you may also stop at any time.

Contact Information

If you have questions about this study, please contact the lead researcher, Daniel Reed at 581-1031 or on FirstClass, or project advisor Michael Wittmann at 581–1237 or on FirstClass. If you have any questions about your rights as a research participant, please contact Gayle Anderson, Assistant to the University of Maine's Protection of Human Subjects Review Board at 581-1498 or on FirstClass.

Appendix B: SET Interview Protocols

SET Coordinator Interview Protocol

Hello, I'm Dan Reed from the MST program. As you know I've asked you here because I'm trying to gather information about the SET student population and how Technical Physics (PHY107/108) addresses the SET students. So, I thought that meeting with you and some of the other faculty in SET might help clarify the context Technical Physics holds within the SET program.

1. As the _____ **program coordinator and an instructor** for this population, I think you might be able to help me to better understand the _______ students. First, **what attributes do you seek within a(n) _____ candidate?**

2. Ok, now setting aside your ideal candidate. Within the ______ population, in general, what **strengths** or positive characteristics do you see, which can be capitalized on within the classroom or in the field?

3. As we all have **weaknesses** to overcome, in this population, what weaknesses do you perceive?

> Over the years, what are some **methods** that you and your fellow _____ faculty have used to work with these weaknesses?

4. I notice that the minimum required **SAT** Verbal score (530) is higher than the Math (~520) for the SET. Can you talk to me a little bit about **what these standards mean to you and the SET?**

5. ______students often begin their first semester at UMaine with Technical Physics. What **skills and abilities** do you see students needing **before they are ready to gain what you wish physics to offer them?**

6. As both a teacher and the _____ coordinator, I believe you may have an interesting take on this question. Do you see a greater value in **Technical Physics** as a mean to **filter** students or a place to **develop particular skills**?

7. From your perspective, what do **you hope** these students **develop by taking a physics course?**

8. To connect with the previous question, I have a two-part question for you:

What physics ideas do you use in your courses?

How do you use these concepts?

9. I'm a(n) _____ **student** coming to you trying to understand **why I need Physics**. What do you say?

SET Director Interview Protocol

Hello, I'm Dan Reed from the MST program. As you know I've asked you here because I'm trying to gather information about the SET student population and how Technical Physics (PHY107/108) addresses the SET students. So, I thought that meeting with you and some of the other faculty in SET might help clarify the context Technical Physics holds within the SET program.

1. As the program director for SET, I thought you might be able to help me understand the student population SET seeks. What do you **look for in a potential SET candidate?**

2. So, that's your ideal student, but how would you describe the students you receive. What are the **strengths** of the SET population? **Weaknesses?**

3. The SET website specifies a minimum required **SAT** Verbal score (530) is higher than the Math (480) for the SET. Can you talk to me a little bit about what these standards **mean to you and the SET?**

4. Now, shifting focus, could you tell me about the **Technical Physics** course and its **development over the years?**

5. As both an instructor and the SET coordinator, I believe you may have an interesting take on this question. Do you see a **greater value** in Technical **Physics** as a mean to **filter** students or a **place to develop particular skills?**

6. Having a strong physics background yourself; can you describe what you hope these students develop by taking a physics course?

7. SET students often begin their **first semester** at UMaine with Technical Physics. What **skills and abilities** do you see as **necessary** for them to **participate in physics and develop how you would hope?**

8. I understand there is a math **placement exam** that entering SET students take. What **role do the results play in selecting initial courses?**

9. So that I can better understand your perspective, can you tell me why **PHY 107** is offered as a **fall course instead of a spring course?**

10. I'm an **SET student** coming to you trying to understand **why I need Physics**. What do you say?

Appendix C: PHY 107 Instructor Interview Protocols

PHY 107 Teaching Assistant Interview Protocol

1. What do you consider to be the critical skills and understanding that an introductory physics course should offer?

2. Can you describe some of the **strengths** you perceive within the PHY 107/108 population? What aspects **do you try to use to your advantage** when you work with the students in this course?

3. Now that you've discussed their strengths, could you please define and discuss how you work with their **weaknesses** that you perceive?

4. As you work within the 107/108 course

    What have you noticed **works well for** these students during **lab?**
    Lab write-up?

    How have you found yourself adjusting your expectations for lab to better work with these students?

    What do you find seems to work well with the tutorials for these students?

    What do they seem to struggle with during tutorials?

5. You know how we're asked to stress the **Socratic dialogue**, do you?
    If not, why not?
    If so, where does it appear to succeed?
    And fail?

6. What specific **skills**, if any, would you like students to have **before they enter PHY** 107?

7. To clarify: what do you think a student should leave an intro physics course with?

8. I'm a 107 student. Why do I need PHY 107/108?

PHY 107 Lecturer Interview Protocol

1. What do you consider to be the critical skills and understanding that an introductory physics course should offer?

   In other words, if nothing else what should a student leave an intro physics course with?

2. Technical Physics (PHY 107) has been developed because the SET students were failing within the other algebra-based and presumably the calculus based courses available. Can you tell me more about what prevented their success and what you mean by failing?

3. Can you describe some of the strengths you perceive within the SET population? What aspects do you try to use to your advantage when you develop your course?

4. Now that you've discussed their strengths, could you please define and discuss how you work with their weaknesses that you perceive?

5. As you developed this Technical Physics course for the SET program, you have adjusted your course to address the concerns for the SET students.

   What changes have you made to your lectures? Homework? Exams? Please explain the thought behind those changes.

   How have you selected the tutorials you use and what do you take into consideration as you alter some of them for the SET students?

   And lab?

6. I know that you stress the Socratic dialogue, and I realize that it has shown promise in other student populations; however, why do you feel that approach is appropriate for this population?

7. What specific skills, if any, would you like students to have before they enter PHY 107?

8. To clarify: what do you think a student should leave an intro physics course with?

Appendix D: Student Interview Protocol

Before we begin, I want to let you know that as we go through this interview, I will avoid using your name. Although it's impersonal, it will add another layer, helping to keep your identity confidential.

Prompts:

Is there any difference between how you want to answer this question and how you think you're supposed to?

So, what's going on here?

What seems hazy? What do you feel you need to help you?

What other real-life or classroom situations did you consider as you thought a bout what's going on?

Follow up questions:

1. What do you feel you **needed to better prepare you** for PHY 107?

2. Is there **anything** in particular you feel that you needed during the course that **we did not offer you?**

3. Did anything within the PHY 107 course structure **better help you learn?** If so, would you mind explaining?

4. Why are you **told physics is important?** Regardless of why others believe you should learn physics; do you think you **developed any useful tools** through PHY 107?

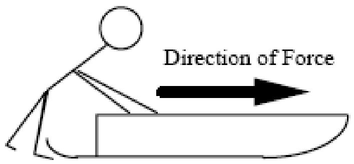
Appendix E: Force and Motion Conceptual Evaluation

FORCE AND MOTION CONCEPTUAL EVALUATION

Directions: Answer questions 1-47 in spaces on the answer sheet. Be sure your name is on the answer sheet. Answer question 46a also on the answer sheet. Hand in the questions and the answer sheet.

A sled on ice moves in the ways described in questions 1-7 below. *Friction is so small that it can be ignored.* A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (**A** through **G**) which would **keep the sled moving** as described in each statement below.

You may use a choice more than once or not at all but choose only one answer for each blank. If you think that none is correct, answer choice **J**.

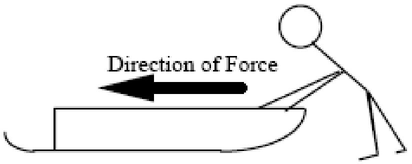


A. The force is toward the **right** and is **increasing** in strength (magnitude).

B. The force is toward the **right** and is of **constant** strength (magnitude).

C. The force is toward the **right** and is **decreasing** in strength (magnitude).

D. No applied force is needed



E. The force is toward the **left** and is **decreasing** in strength (magnitude).

F. The force is toward the **left** and is of **constant** strength (magnitude).

G. The force is toward the **left** and is **increasing** in strength (magnitude).

___1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?

___2. Which force would keep the sled moving toward the right at a steady (constant) velocity?

___3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant acceleration)?

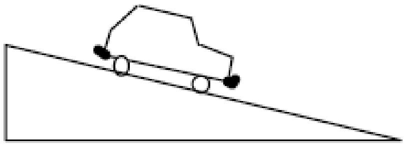
___4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?

___5. The sled was started from rest and pushed until it reached a steady (constant) velocity toward the right. Which force would keep the sled moving at this velocity?

___6. The sled is slowing down at a steady rate and has an acceleration to the right. Which force would account for this motion?

___7. The sled is moving toward the left. Which force would slow it down at a steady rate (constant acceleration)?

Questions 8-10 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. *Friction is so small it can be ignored.*



Use one of the following choices (**A** through **G**) to indicate the **net force** acting on the car for each of the cases described below. Answer choice **J** if you think that none is correct.

Ⓐ Net **constant** force **down** ramp
Ⓑ Net **increasing** force **down** ramp
Ⓒ Net **decreasing** force **down** ramp
Ⓓ Net force zero
Ⓔ Net **constant** force **up** ramp
Ⓕ Net **increasing** force **up** ramp
Ⓖ Net **decreasing** force **up** ramp

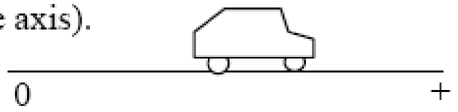
_______8. The car is moving up the ramp after it is released.
_______9. The car is at its highest point.
_______10. The car is moving down the ramp.

Questions 11-13 refer to a coin which is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the force acting on the coin for each of the cases described below. Answer choice **J** if you think that none is correct. **Ignore any effects of air resistance.**

A. The force is **down** and constant.
B. The force is **down** and increasing
C. The force is **down** and decreasing
D. The force is zero.
E. The force is **up** and constant.
F. The force is **up** and increasing
G. The force is **up** and decreasing

_______11. The coin is moving upward after it is released.
_______12. The coin is at its highest point.
_______13. The coin is moving downward.

Questions 14-21 refer to a toy car which can move to the right or left along a horizontal line (the positive part of the distance axis).



Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (**A** through **H**) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

__14. The car moves toward the right (away from the origin) with a steady (constant) velocity.

__15. The car is at rest.

__16. The car moves toward the right and is speeding up at a steady rate (constant acceleration).

__17. The car moves toward the left (toward the origin) with a steady (constant) velocity.

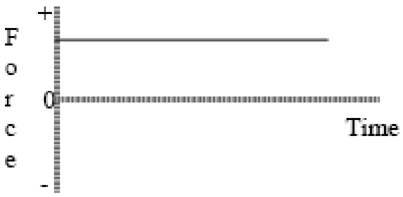
__18. The car moves toward the right and is slowing down at a steady rate (constant acceleration).

__19. The car moves toward the left and is speeding up at a steady rate (constant acceleration).

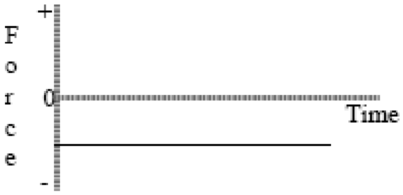
__20. The car moves toward the right, speeds up and then slows down.

__21. The car was pushed toward the right and then released. Which graph describes the force after the car is released.

A



B

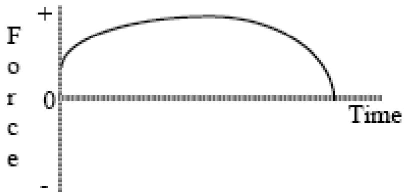


C

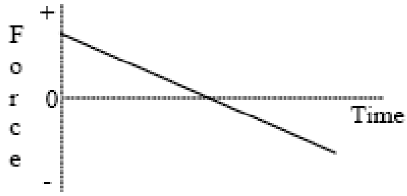
D

E

F



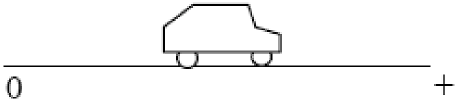
G



H

J None of these graphs is correct.

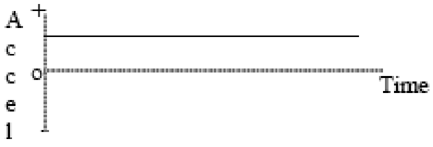
Questions 22-26 refer to a toy car which can move to the right or left on a horizontal surface along a straight line (the + distance axis). The positive direction is to the right.



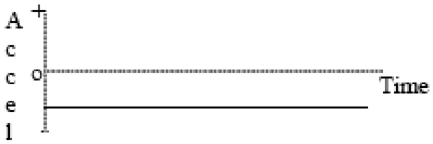
Different motions of the car are described below. Choose the letter (**A** to **G**) of the **acceleration time** graph which corresponds to the motion of the car described in each statement.

You may use a choice more than once or not at all. If you think that none is correct, answer choice **J**.

A



B

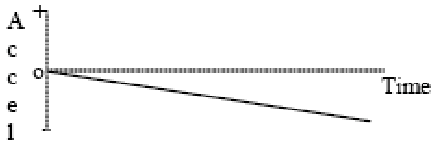


C

D

E

F



G

J None of these graphs is correct.

_____22. The car moves toward the right (away from the origin), speeding up at a steady rate.

_____23. The car moves toward the right, slowing down at a steady rate.

_____24. The car moves toward the left (toward the origin) at a constant velocity.

_____25. The car moves toward the left, speeding up at a steady rate.

_____26. The car moves toward the right at a constant velocity.

Questions 27-29 refer to a coin that is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of the following choices (**A** through **G**) to indicate the acceleration of the coin during each of the stages of the coin's motion described below. Take **up** to be the **positive** direction. Answer choice **J** if you think that none is correct.

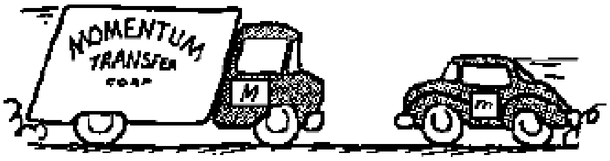
A. The acceleration is in the negative direction and constant.
B. The acceleration is in the negative direction and increasing
C. The acceleration is in the negative direction and decreasing
D. The acceleration is zero.
E. The acceleration is in the positive direction and constant.
F. The acceleration is in the positive direction and increasing
G. The acceleration is in the positive direction and decreasing

___27. The coin is moving upward after it is released.
___28. The coin is at its highest point.
___29. The coin is moving downward.

Questions 30-34 refer to collisions between a car and trucks. For each description of a collision (30-34) below, choose the one answer from the possibilities **A** though **J** that best describes the forces between the car and the truck.

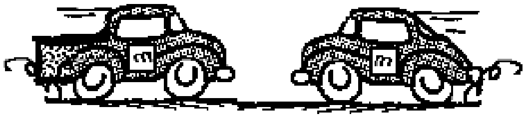
A. The truck exerts a greater amount of force on the car than the car exerts on the truck.
B. The car exerts a greater amount of force on the truck than the truck exerts on the car.
C. Neither exerts a force on the other; the car gets smashed simply because it is in the way of the truck.
D. The truck exerts a force on the car but the car doesn't exert a force on the truck.
E. The truck exerts the same amount of force on the car as the car exerts on the truck.
F. Not enough information is given to pick one of the answers above.
J. None of the answers above describes the situation correctly.

In questions 30 through 32 the truck is ***much heavier*** *than the car .*



______30. They are both moving at the same speed when they collide. Which choice describes the forces?
______31. The car is moving much faster than the heavier truck when they collide. Which choice describes the forces?
______32. The heavier truck is standing still when the car hits it. Which choice describes the forces?

In questions 33 and 34 the truck is a small pickup and is the ***same weight*** *as the car.*



______33. Both the truck and the car are moving at the same speed when they collide. Which choice describes the forces?

______34. The truck is standing still when the car hits it. Which choice describes the forces?

Questions 35-38 refer to a large truck which breaks down out on the road and receives a push back to town by a small compact car.

Pick one of the choices **A** through **J** below which correctly describes the forces between the car and the truck for each of the descriptions (35-38).

A. The force of the car pushing against the truck is equal to that of the truck pushing back against the car.

B. The force of the car pushing against the truck is less than that of the truck pushing back against the car.

C. The force of the car pushing against the truck is greater than that of the truck pushing back against the car.

D. The car's engine is running so it applies a force as it pushes against the truck, but the truck's engine isn't running so it can't push back with a force against the car.

E. Neither the car nor the truck exert any force on each other. The truck is pushed forward simply because it is in the way of the car.

J. None of these descriptions is correct.

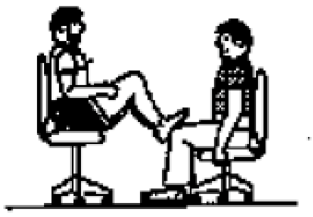
______35. The car is pushing on the truck, but not hard enough to make the truck move.

______36. The car, still pushing the truck, is **speeding up** to get to cruising speed.

______37. The car, still pushing the truck, is at cruising speed and continues to travel at the **same speed**.

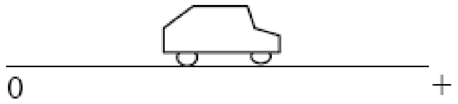
______38. The car, still pushing the truck, is at cruising speed when the truck puts on its brakes and causes the car to **slow down**.

____39. Two students sit in identical office chairs facing each other. Bob has a mass of 95 kg, while Jim has a mass of 77 kg. Bob places his bare feet on Jim's knees, as shown to the right. Bob then suddenly pushes outward with his feet, causing both chairs to move. In this situation, while Bob's feet are in contact with Jim's knees,

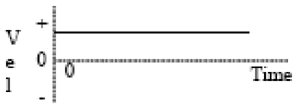


A. Neither student exerts a force on the other.
B. Bob exerts a force on Jim, but Jim doesn't exert any force on Bob.
C. Each student exerts a force on the other, but Jim exerts the larger force.
D. Each student exerts a force on the other, but Bob exerts the larger force.
E. Each student exerts the same amount of force on the other.
J. None of these answers is correct.

Questions 40-43 refer to a toy car which can move to the right or left along a horizontal line (the positive portion of the distance axis). The positive direction is to the right.

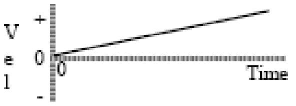


Choose the correct velocity-time graph (**A** - **G**) for each of the following questions. You may use a graph more than once or not at all. If you think that none is correct, answer choice **J**.

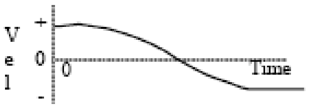
A


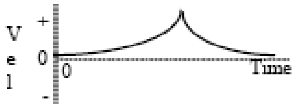
B


C


D


E


F


G


H


J None of these graphs is correct.

___40. Which velocity graph shows the car moving toward the right (away from the origin) at a steady (constant) velocity?
___41. Which velocity graph shows the car reversing direction?
___42. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?
___43. Which velocity graph shows the car increasing its *speed* at a steady (constant) rate?

A sled is pulled up to the top of a hill. The sketch above indicates the shape of the hill. At the top of the hill the sled is released from rest and allowed to coast down the hill. At the bottom of the hill the sled has a speed v and a kinetic energy E (the energy due to the sled's motion). Answer the following questions. ***In every case friction and air resistance are so small they can be ignored.***

__44. The sled is pulled up a **steeper** hill of the **same** height as the hill described above. How will the velocity of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill? Choose the best answer below.

A. The speed at the bottom is greater for the steeper hill.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill because the sled travels further.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

__45. Compare the kinetic energy (energy of motion) of the sled at the bottom for the original hill and the steeper hill in the previous problem. Choose the best answer below.

A. The kinetic energy of the sled at the bottom is greater for the steeper hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

__46. The sled is pulled up a **higher** hill that is **le**ss steep than the original hill described before question 44. How does the speed of the sled at the bottom of the hill (after it has slid down) compare to that of the sled at the bottom of the original hill?

A. The speed at the bottom is greater for the higher but less steep hill than for the original.
B. The speed at the bottom is the same for both hills.
C. The speed at the bottom is greater for the original hill.
D. There is not enough information given to say which speed at the bottom is faster.
J. None of these descriptions is correct.

46a. Describe in words your reasoning in reaching your answer to question 46. (**Answer on the answer sheet** and use as much space as you need)

_47. For the higher hill that is less steep, how does the kinetic energy of the sled at the bottom of the hill after it has slid down compare to that of the original hill?

A. The kinetic energy of the sled at the bottom is greater for the higher but less steep hill.
B. The kinetic energy of the sled at the bottom is the same for both hills.
C. The kinetic energy at the bottom is greater for the original hill.
D. There is not enough information given to say which kinetic energy is greater.
J. None of these descriptions is correct.

Appendix F: Key for All Survey Question Clusters

Table 28: FMCE Clusters

	Velocity	Acceleration	Newton's 1st and 2nd laws	Newton's 3rd law	Energy
FMCE items	40-43	22-29	1-4, 7-14, 16-21	30-32, 34, 36, 38	44-47

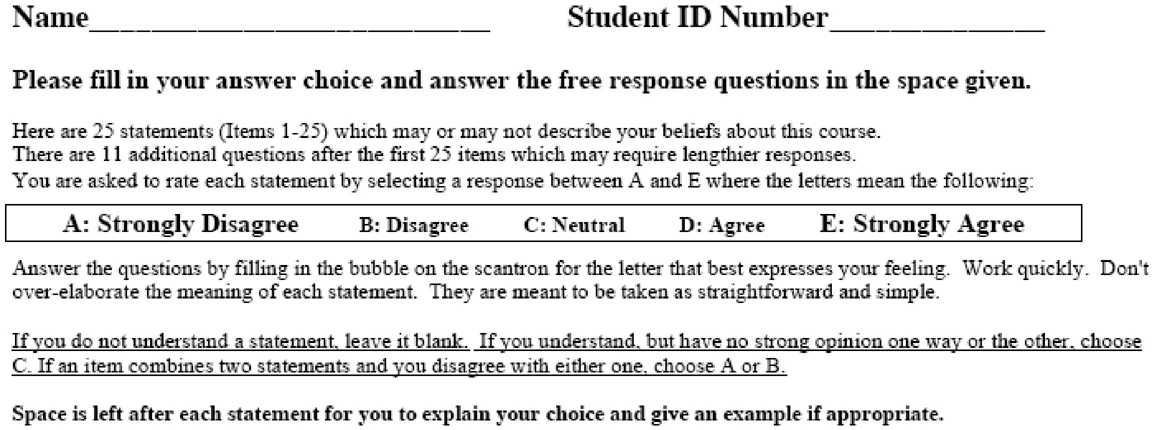
Table 29: MPEX2 Clusters

	Coherence	Concepts	Independence	Coherence		Independence	
				Math Link	Reality Link	Epistemology	Personal Metacognition
MPEX2 items	3, 4, 6, 8, 10, 13, 15, 19, 21, 23, 27, 28	5, 9, 16, 18, 19, 23, 24, 28, 30	2, 7, 11, 12, 14, 17, 20, 22, 25, 29, 31, 32	3, 10, 28	4, 8, 15, 21	2,11, 12, 15, 20, 22, 25, 29, 31, 32	7, 14, 17

Table 30: Math Diagnostic Clusters

	Isolating Variables	Simultaneous Equations	Graphing	Fraction Addition	Trigonometry	Scientific Notation	Letters as Constants
Math Diagnostic Items	1, 2, 15	5, 6, 7, 12, 24, 30	9, 19, 37, 38	13, 23, 31, 35	3, 8, 20, 25, 28, 33, 34, 36	10, 22, 26, 32	16, 17, 18

Appendix G: Maryland Physics Expectations Survey 2: Version 1.3



Name_________________________ **Student ID Number**_____________

Please fill in your answer choice and answer the free response questions in the space given.

Here are 25 statements (Items 1-25) which may or may not describe your beliefs about this course.
There are 11 additional questions after the first 25 items which may require lengthier responses.
You are asked to rate each statement by selecting a response between A and E where the letters mean the following:

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

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

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

Space is left after each statement for you to explain your choice and give an example if appropriate.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Two students are talking about their experiences in class:

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

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

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

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

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

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

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

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

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

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

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

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

29) Consider the following question from a popular textbook:

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

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

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

Roy and Theo are working on a homework problem.

Roy:	"I remember in the book it said that anything moving in a circle has to have a centripetal acceleration."
Theo:	"But if the particle's velocity is constant, how can it be accelerating? That doesn't make sense."
Roy:	"Look, right here, under 'Uniform Circular Motion' – here's the equation, $a=v^2/r$. That's what we need for this problem."
Theo:	"But I know that to have an acceleration, we need a change in velocity. I don't see how the velocity is changing. That equation doesn't seem right to me."

What would be the advantages (if any) of working with Roy?

____

____

What would be the advantages (if any) of working with Theo?

____

____

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

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

32.) Several students are talking about group work.

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

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

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

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

For the next two questions, please write your answer in the space provided.

Many students report that they sometimes come away from a lecture feeling like they understand a given topic or concept; but when they try to complete a homework problem on that topic, they get stuck. Why do you think this happens?

____

____

____

____

What, if anything, did you get out of this course that will help you in your chosen profession two years from now?

____

____

____

____

33.) Why are you taking this course?

- (a) I'm a CMT. It's required.
- (b) I'm an EET. It's required.
- (c) I'm an MET. It's required.
- (d) I'm an SVT. It's required.
- (e) Other: (please specify): ______________________________

34.) On a scale of 1 to 5, I would rate my overall experience in previous science courses as:

(A) very negative (B) somewhat negative (C) neutral (D) somewhat positive (E) very positive

35.) I feel that my ability to learn physics is:

- (A) well above average in this class (in the top 10% of this class)
- (B) better than average for this class
- (C) about average for this class
- (D) below average for this class
- (E) well below average for this class

36.) Compared to my ability to learn physics, my ability to learn other subjects is:

- (A) much greater
- (B) somewhat greater
- (C) about the same
- (D) somewhat less
- (E) much less

Appendix H: Math Diagnostic

Name: ________________ Student ID Number:______________

Diagnostic Math Exam for Physics 107[41]

Participation alone will determine your lab grade for this period; however, we do request your full effort.

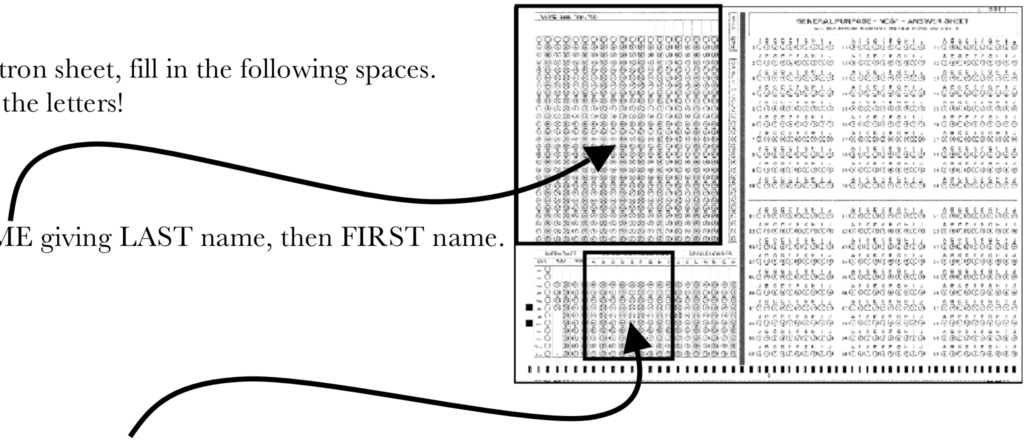
The purpose of this exam is to accurately assess your mathematical ability and refresh your memory of some math you will continue to see throughout your scholarly and professional careers. In addition, understanding your current ability will help us better work with you as you learn physics.

To make the results of this exam meaningful, we ask you to take it under the following conditions:

Use no aids, such as books or calculators;
Do not guess at random, instead please leave the answer blank for those questions you cannot solve at the moment: answers that fail to reflect your understanding helps no one.

As usual, use a number 2 *pencil* to fill in the scantron answer sheet.

5. On the scantron sheet, fill in the following spaces.
Be sure to bubble in the letters!



A. Fill out NAME giving LAST name, then FIRST name.

B. Write your STUDENT IDENTIFICATION NUMBER in the space marked "identification number".
The first digit of your student ID number should go in box A.

C. You can ignore additional information spaces.

6. Please transfer all of your answers to the scantron answer sheet; use the scrap paper provided for your work, and please indicate the question number that your work goes with.
Thank you, and good luck.

---

[41] This math test is an adapted version of material copyrighted by Professor H. Thomas Hudson of University of Houston

DIAGNOSTIC TEST

1. What is the value of x in the expression

$$x = p(p + q) + 4$$

if $p = -2$ and $q = 5$?

a. -2   b. -3   c. 4   d. -6   e. 18

2. Given $x + 2 = 2(x - 3)$, what is the value of x?

a. 2   b. 3   c. 4   d. 6   e. 8

3. $\sqrt{15^2 - 9^2}$ = ____________.

a. 6   b. $\sqrt{6}$ c. 12   d. $\sqrt{12}$ e. $\sqrt{135}$

4. Express a speed of 30 kilometers per hour in meters/second.

a. 108,000   b. 0.008   c. 0.03   d. 3.0   e. 8.3

5. What is the value of x in the following equations?

$$x + 4t = 2$$
$$2x - 2 = t + 2$$

a. -2/9   b. 2   c. 1/2   d. 4   e. 1/4

6. Find y as a function of x from the following equations.

$$2x - t = 2$$
$$y - 4 = 3t$$

a. $y = 3x + 4$ b. $y = 10 - 3x$ c. $y = 3x + 6$

d. $y = 4 - 6x$ e. $y = 6x - 2$

7. Find z as a function of t from the following equations.

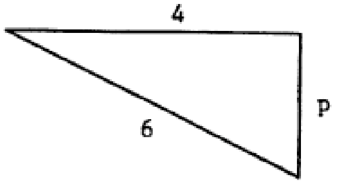
$$12 + s = t^2$$

$$2s = 3z$$

a. $z = 3t^2 - 12$ b. $z = (2/3)t^2 - 8$ c. $z = (1/3)t^2 - 12$

d. $z = (2/3)t^2 + 24$ e. $z = 3t^2 + 6$

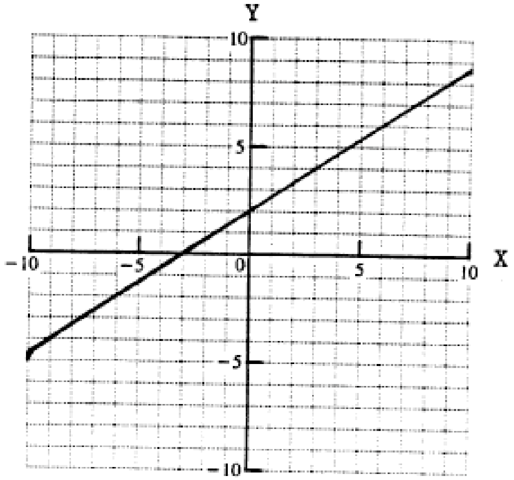
8. For the triangle illustrated, what is p?



a. $\sqrt{2}$ b. 2 c. $\sqrt{10}$

d. 10 e. $\sqrt{20}$

9. What is the slope of the line at $x = 6$?



a. 1

b. 1.5

c. 0.7

d. -1

e. 6

10. $\frac{12 \times 10^8}{2 \times 10^{-2}} =$ ________.

a. 6×10^{-4} b. 10×10^{10} c. 10×10^{-10}

d. 6×10^{10} e. 10×10^{6}

11. If the angle $A = 4\pi/6$ radians, what is the value of A in degrees?

a. 60^o b. 120^o c. 90^o d. 45^o e. 210^o

12. A mother is five years more than twice as old as her daughter. The combined ages of mother and daughter totals 41 years. How old is the mother?

a. 18 years b. 21 years c. 23 years d. 29 years e. 36 years

13. $\frac{3}{14} + \frac{7}{6} =$ ________.

a. 29/21   b. 21/20   c. 10/21   d. 18/49   e. 5/21

14. What is the value of x in the equation $x^2 - 5x - 3 = 0$?

a. $(-1 \pm \sqrt{14})/10$ b. $(3 \pm \sqrt{28})/2$ c. $(5 \pm \sqrt{37})/2$

d. $(-3 \pm \sqrt{22})/6$ e. $(1 \pm \sqrt{23})/7$

15. Given $a = -2$, $b = 3$, $c = -5$, what is the value of $a(b - c) + bc^2$?

a. -91   b. -79   c. 79   d. 71   e. 59

16. Solve for q in the following expression, treating A, B and C as constants: $A(q - B) = Bq - C$.

a. $q = (B - C)/(A + B)$ b. $q = (AB - C)/(A - B)$

c. $q = (B + C)/AB$ d. $q = (A + B)/(AB - C)$

e. $q = (A + B)/(B - C)$

17. Solve for y as a function of x from the following equations, treating R, S, and T as constants.

$$Rx - St = T$$
$$y = S(St + T)$$

a. $y = SRx$ b. $y = S^2Rx + ST$ c. $y = S^2Rx - 2ST$

d. $y = SRx - ST$ e. $y = (SRx - S^2 - ST^2)/T$

18. Given $ap = bt^2$ and $bq = at$, where a and b are constants, what is q as a function of p?

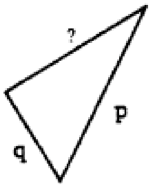
a. $q = p\sqrt{b/a}$ b. $q = (a/b)\sqrt{ap/b}$ c. $q = p^2\sqrt{a/b}$

d. $q = p$ e. $q = \sqrt{ap/b}$

19. What is the intercept (i.e., the value of x when y = 0) of the straight line through the points (x = 6, y = -1) and (x = 3, y = 2)?

a. 3   b. 5   c. -3   d. -5   e. 1

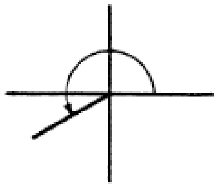
20. What is the length of the unknown side of the right triangle illustrated in terms of p and q?



a. $\sqrt{q} - \sqrt{p}$ b. $\sqrt{p} - \sqrt{q}$ c. $\sqrt{p^2 + q^2}$

d. $\sqrt{p^2 - q^2}$ e. $\sqrt{q^2 - p^2}$

21. How many radians in 210°?



a. $5\pi/12$ b. $7\pi/12$ c. $5\pi/7$

d. $6\pi/7$ e. $7\pi/6$

22. $(6.5 \times 10^{-4}) - (1.37 \times 10^{-3}) =$ __________.

a. 5.1×10^{-3} b. 5.4×10^{-3} c. 5.1×10^{-4}

d. -7.2×10^{-4} e. -6.4×10^{-4}

23. $\frac{a + b}{a} + \frac{b - a}{b} =$ ____________.

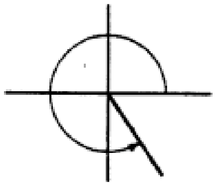
a. 2 b. $(b^2 + 2ab - a^2)/ab$ c. $2/ab$

d. $(a^2 + 2ab + b^2)/2ab$ e. $2a/b$

24. Water from hose A alone can fill a certain tank in 15 hours. When collecting water from both hose A and hose B, the tank is filled in only 6 hours. How long will it take to fill the tank when it is collecting water only from hose B?

a. 4.5 hours b. 8 hours c. 9 hours d. 10 hours e. 11.5 hours

25. Cos 300° = __________.



a. + cos 60° b. - cos 60°
c. + cos 30° d. - cos 30°
e. none of the above

26. $(4 \times 10^{6}) \times (3 \times 10^{-4}) =$ ________.

a. 12×10^{-24} b. 1.3×10^{10} c. 0.75×10^{10}

d. 75 e. 1200

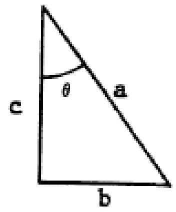
27. Solve for x in the equation below, treating p, q and r as constants:

$$qx^2 - rx + p = 0$$

a. $(-r \pm \sqrt{q^2 + 4rp})/2q$
b. $(-q \pm \sqrt{r^2 - 4pq})/2q$
c. $(p \pm \sqrt{r^2 - 4qr})/2p$
d. $(r \pm \sqrt{r^2 - 4pq})/2q$
e. $(-p \pm \sqrt{q^2 - 4rp})/2r$

28. Cos θ = _____.

a. a/c
b. c/a
c. b/c
d. a/b
e. b/a



29. Express a rotation rate of 5 rotations per minute in degrees per second.

a. 0.83
b. 30
c. 1800
d. 300
e. 108,000

30. Solve for y in the following equations.

$$2y - 5 = z$$
$$y - 2z = 1$$

a. 1
b. 2
c. 3
d. 4
e. 5

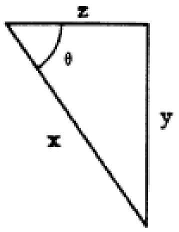
31. $\dfrac{xy}{z^2x} + \dfrac{zx}{zy} =$ __________.

a. y/z
b. x/z^2
c. $(xy + z^2x^2)/z^2y$
d. $(xy + z)/(z^2x + zy)$
e. $(y^2 + z^2x)/z^2y$

32. $3.48 \times 10^5 + 1.26 \times 10^4 =$ __________.

a. 3.6×10^5
b. 4.74×10^5
c. 3.6×10^4
d. 1.6×10^5
e. 1.6×10^4

33. Tan θ = _____.



a. x/z
c. z/y
e. y/x

b. x/y
d. y/z

34. $\sqrt{9^2 + 6^2}$ = __________.

a. $\sqrt{9} + \sqrt{6}$ b. $\sqrt{15}$ c. $\sqrt{54}$ d. $\sqrt{117}$ e. 15

35. $\frac{2x - y}{x} + \frac{x + y}{y}$ = ___________.

a. 3x/y b. $(x^2 + 3xy - y^2)/xy$ c. $(2x^2 - y^2)/xy$

d. $2x^2 + y^2 - 3xy$ e. 2 - y + x

36. sin 100° = _________________.

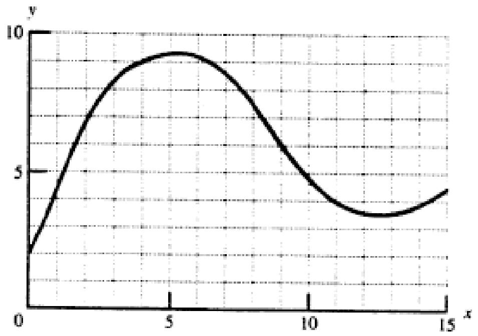
a. sin 10° b. -sin 10° c. -sin 80°

d. sin 80° e. none of these.

37. What is the (approximate) slope of the curve at x = 11?

a. -0.2
c. +2
e. -1

b. +1
d. -0.6



38. What is the value of q when x = 0 on the line that goes through the points (x = 3, q = 10) and (x = -3, q = -2)?

a. 2 b. 4 c. 13 d. 17 e. -17

Appendix I: UMaine Math Placement Test: Part II

1. $\sqrt{48a^8b^{16}} =$

(A) $24a^8b^{16}$ (B) $4a^6b^{14}\sqrt{3}$ (C) $24a^4b^8$ (D) $4a^4b^8$ (E) $4a^4b^8\sqrt{3}$

2. $(6a^3b)(-8a^4b^2) =$

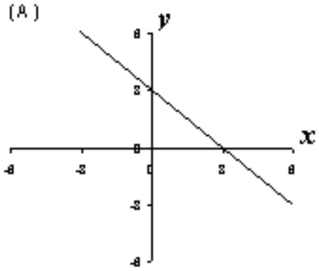
(A) $-2a^{12}b^2$ (B) $-48a^7b^3$ (C) $-48a^{12}b^2$ (D) $-2a^{-1}b^{-1}$ (E) $48a^7b^2$

3. $2^0 3^2 =$

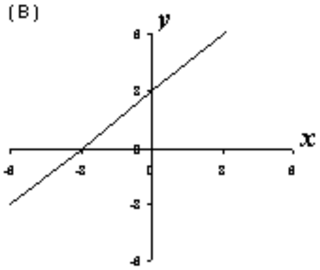
(A) 0 (B) 6 (C) 9 (D) 12 (E) 36

4. Of the following, which best represents the graph of $x + y = 3$?

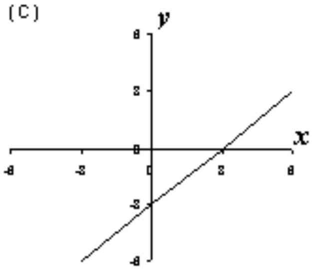
(A)



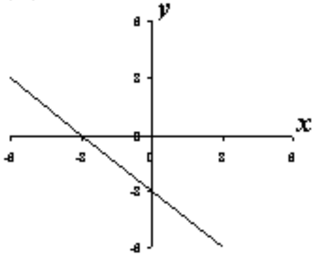
(B)



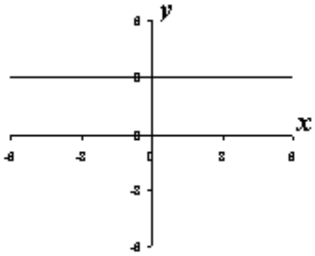
(C)



(D)



(E)



5. $\dfrac{6x^4w - 2xw^4}{2xw} =$

(A) 2 (B) $3x^3 - 2xw^4$ (C) $6x^4w - w^3$ (D) $3x^3 - w^3$ (E) $2x^3w^3$

6. $\dfrac{x^2 - 9}{2x} \cdot \dfrac{24}{4x - 12} =$

(A) $\dfrac{9}{4}$ (B) $3(x+3)$ (C) 9 (D) $\dfrac{3(x+3)}{x}$ (E) $\dfrac{3(x-3)}{x}$

7. What are all the values of t for which $|-t| = 6$?

(A) 6 (B) -6 (C) 6 and -6 (D) $6, 0,$ and -6 (E) No such t exists

8. If $x = \dfrac{4}{7}$ then $x^{-2} =$?

(A) $-\dfrac{49}{16}$ (B) $-\dfrac{8}{14}$ (C) $-\dfrac{16}{49}$ (D) $\dfrac{14}{8}$ (E) $\dfrac{49}{16}$

9. $\dfrac{8}{a} - \dfrac{5}{b} =$

(A) $\dfrac{3}{a+b}$ (B) $\dfrac{3}{a-b}$ (C) $\dfrac{3}{ab}$ (D) $\dfrac{8b-5a}{ab}$ (E) $\dfrac{8a-5b}{ab}$

10. The solutions of the equation $3x^2 + x - 30 = 0$ are

(A) -3 and $-\dfrac{10}{3}$ (B) -3 and $\dfrac{10}{3}$ (C) 3 and -10 (D) 3 and $-\dfrac{10}{3}$ (E) 3 and $\dfrac{10}{3}$

11. The inequality $|5-y|<5$ is equivalent to

(A) $y<0$ (B) $y<10$ (C) $0<y<10$ (D) $y>0$ (E) $y>10$

12. Which of the following are factors of x^4-81?

I.. $x-3$ II. $x+3$ III. x^2+9

(A) I only (B) II only (C) III only (D) I and II only (E) I, II, and III

13. If $\log_{10} y = 4$ then $y=$?

(A) 10,000 (B) 1,000 (C) 10 (D) $\frac{4}{10}$ (E) $\frac{1}{10{,}000}$

14. In the system of equations $\begin{cases} 2x + 6y = 5 \\ x - 3y = 8 \end{cases}$

(A) $x=-\frac{11}{12}$ (B) $x=0$ (C) $x=\frac{5}{2}$ (D) $x=\frac{13}{4}$ (E) $x=\frac{21}{4}$

15. $(27)^{2/3}(81)^{1/4}=$

(A) 3 (B) 9 (C) 27 (D) 81 (E) 243

16. One of the solutions of the equation $x^2+4x=-13$ is

(A) -17 (B) 2 (C) $3i$ (D) $-2+3i$ (E) -13

17. The graph of the system of equations $\begin{cases} x - 2y = 6 \\ 3x + 6y = 0 \end{cases}$ consists of

(A) two lines which intersect at the point $\left(3, -\frac{3}{2}\right)$
(B) two lines which intersect at the point $(2, -2)$
(C) two lines which intersect at the point $(-2, 2)$
(D) two distinct parallel lines
(E) one line

18. If $8^x = 3$ then $x =$

(A) $\frac{3}{8}$ (B) $\frac{8}{3}$ (C) $\log_8 3$ (D) $\log_3 8$ (E) $\log_{10}\left(\frac{3}{8}\right)$

19. The inequality $x^2 - 9x < 10$ is equivalent to

(A) $2 < x < 5$ (B) $-1 < x < 10$ (C) $-2 < x < 5$ (D) $x < 2$ or $x > 5$ (E) $x < -1$ or $x > 10$

20. If $f(x) = x^3 + 9$ then $f(x-h) =$

(A) $x^3 - h^3 + 9$ (B) $(x-h)^3 + 9$ (C) $(x-h+9)^3$ (D) $x^3 + 9 - h$ (E) $(x^3+9) - (h^3+9)$

Appendix J: Math problem in Physics Context

Your dad needs a hand installing a new window for the second story bathroom; however, your only ladder is 6' long (i.e. too short). Fortunately, you're clever enough to see the balcony near the bathroom, and devise a strategy to get out to the window.

You decide to take a plank, lay it across the balcony rail, extend it out to the window, and use a rope to tie the plank down to the other side of the balcony. The rope ensures that the plank won't move as you step out onto it (a system in *mechanical equilibrium*, i.e. no rotation, no translation).
Use the provided x-y coordinate system for all work and assume you weigh 700 N and θ=35°.

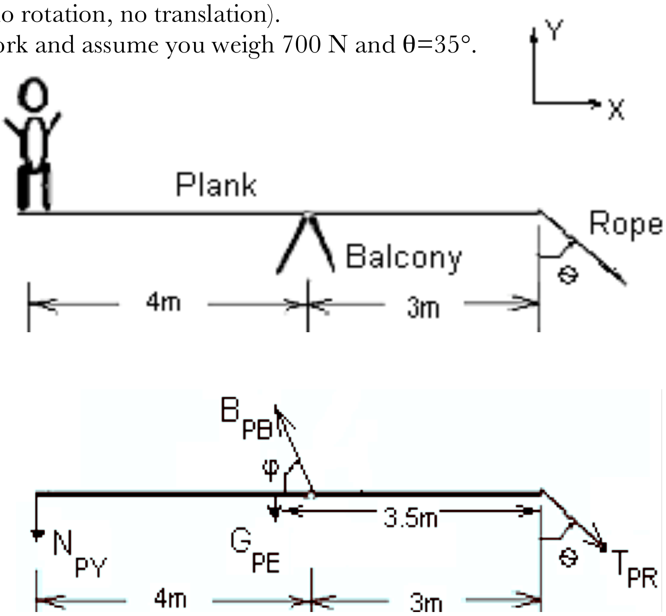


Figure: Plank System and its Free Body Diagram

As you begin walking from the balcony toward the window, will the Tension on the plank by the rope…

increase, decrease, or remain the same?

Circle one. (No explanation necessary.)

b) The plank is in mechanical equilibrium as shown (i.e. no rotation, no translation).
Find the Tension on the plank by the rope (T_{PR}) using a plank weight of 210 N. (Show all work.)

c) After reaching the end of the plank, you're not sure if you trust it to support both you and the new window. So, you decide to *change to a thicker plank* of identical length and width. If the *thicker* plank weighs 280 N and your new Tension on the plank by the rope (new T_{PR}) is 1200 N, then… Find the *magnitude* of the Force on the plank by balcony (B_{PB}). (Show all work.)

d) Will the angle ϕ be the same as the angle θ?

i. Explain why or why not.

ii. If ϕ is different than θ, calculate ϕ. (Show all work.)

Appendix K: SET Math Instructor Regarding Math Diagnostic

1. Do fine
2. [Skipped, but came back and said ¾]
3. Should be fine. If one is a variable however…
5. Simultaneous equations solving for x

I: What do you think would throw them off?

Probably about 60% would try to solve by substitution. 40% would solve by elimination (you know multiply by 2 and add the equations together).

The algebra involved, they'd probably make a sign error or an arithmetic error to keep them from succeeding.

7. (question 7 from large test) Simultaneous… terminology
   z as a function of t, like I was saying earlier. Even the students who could do the algebra might not understand the instructions as to what they were trying to accomplish.
8. 2/3 could figure this out
12. this would give them trouble. ¼ to 1/5 because it's an applied problem. They have to come up with. They could try by trial and error. Those who couldn't put it into an equation.
15. Just a numerical evaluation a fairly high percentage 4/5. You've got some negative signs in there, might throw a few curves but that's about it.
    Just arithmetic order of operations they do fairly well, but once you start involving algebraic like square roots in with the arithmetic or other functions like trig functions or exp. Or log functions. Their order of operations kind of slips away from them.
16. ¼ just because it requires factoring. You could multiply out group terms, but that piece there would stump a few.
17. About ½ (this is problem 17 from the whole diagnostic). [What makes this easier?] For this first equation, I think it's a single step substitution. So it's the number of steps. Whereas up here is probably a 4 to 5 step. Number of steps is again a very…
18. ¼ to 1/3. [What made 18 more difficult than 17?] The squared variable instead of linear is one. The constants being capital letters up here vs. all lower case down here. That is actually something that makes it a little more complicated. Because visually it distinguishes between the stuff that's important and the stuff that's not, right?
20. 1/3 would get this, but given multiple choice, I'd say ½. Pythagorean theorem. [why 1/3 if not multiple choice?] If the choices aren't there they really need to recognize where to get started and when they see the choices, they see the square root and that kind of tips them off that you know I'm going to do squares and square roots. You know because their first attempt at anything is a linear attempt. And if the linear attempt doesn't work then you start to think about squares and things like that.
24. 1/5 maybe. We do problems like that in 151. [Do you do many word problems like this in 151?] We do at the beginning of the semester we do something on applied problems. Chapter 3 we go through a whole bunch of different word problems. And they'll see problems like that in successive semesters.
25. ½ about ½ or a little less. Because it's not the value. If they're coming up with the number that would be one thing.
28. ¾ even though the triangle is twisted.
30. 1/2 just another substitution. The minus sign might get some of them.
33. ¾. Similar to number 2. Without calculators 15^2 might give some of them trouble.
34. 2/3 to ¾. Most would get this probably 80%. Some of their mental arithmetic abilities, some of them can do a lot but, others just can't do 2 digit subtraction without the machine.
36. A little less than ½. Sin 100. Ah this one you didn't provide the picture so wouldn't be quite as successful.

Appendix L: MPEX2 Cluster Descriptions

Table 31: Overarching Attitude/Expectation Clusters*Overarching

	Coherence	Concepts	Independence
Favorable	Believes physics needs to be considered as a connected, consistent framework.	Stresses understanding of the underlying ideas and concepts	Takes responsibility for constructing own understanding.
Unfavorable	Believes physics can be treated as unrelated facts or "pieces."	Focuses on memorizing and using formulas	Takes what is given by authorities (teacher, text) without evaluation
MPEX2 Items	3, 4, 6, 8, 10, 13, 15, 19, 21, 23, 27, 28	5, 9, 16, 18, 19, 23, 24, 28, 30	2, 7, 11, 12, 14, 17, 20, 22, 25, 29, 31, 32

Table 32: Embedded Attitude/Expectation Clusters

	Coherence*		Independence**	
	Math Link	Reality Link	Epistemology	Personal Metacognition
Favorable	Considers mathematics as a convenient way of representing physical phenomena.	Believes ideas learned in physics are relevant and useful in a wide variety of real contexts	Believes in the importance of resolving things for one's self as opposed to expecting the authority's edict to resolve everything without reflecdtion	Believes that one's own awareness of physics can guide them through unknown territories or at least show them their current limit
Unfavorable	Views physical phenomena and corresponding math expressions as independent with little relationship between them.	Believes ideas learned in physics has little relation to experiences outside the classroom	Expects an authority to resolve any inconsistencies, only needs to remember what came out of the authority's black box	Believes that only an external source can explain physics and the appropriateness of an answer
MPEX2 Items	3, 10, 28	4, 8, 15, 21	2,11, 12, 15, 20, 22, 25, 29, 31, 32	7, 14, 17

*(Saul & Redish, 1998)

**Inferred from statement clusters from MPEX2 scoring template

Appendix M: Statistical Results for All Indicators for Normalized Gain

Table 33: All Indicators for Square root of <*g*> on the FMCE

	p-value[42]	R^2
FMCE-Pre	**0.002**	0.144
Math Diagnostic Clusters	0.758	0.001
Entire Math Diagnostic	0.329	0.016
SAT-Math	0.135	0.041
SAT-Verbal	0.422	0.012
MPEX2 Favorable Pre-	**0.005**	0.126
MPEX2 Favorable Post-	**0.029**	0.077
MPEX2 Unfavorable Pre-	0.198	0.027
MPEX2 Unfavorable Post-	0.092	0.046
MPEX2 Favorable Pre-Coherence Cluster	**0.004**	0.128
MPEX2 Favorable Post-Coherence Cluster	**0.015**	0.096
MPEX2 Favorable Pre-Concepts Cluster	**0.002**	0.147
MPEX2 Favorable Post-Concepts Cluster	0.075	0.052
MPEX2 Favorable Pre-Independence Cluster	0.228	0.024
MPEX2 Favorable Post-Independence Cluster	0.1097	0.042
MPEX2 Favorable Pre-Coherence + Concept	**3.79E-4**	0.269
MPEX2 Favorable Post-Coherence + Concept	**0.031**	0.141

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[42] Statistically significant p-values (<0.05) are indicated by bold script.

Appendix N: Statistical Results for All Indicators for Pre-instruction FMCE Scores

Table 34: All Indicators for Square Root of pre-instruction FMCE

	p-value	R^2
Math Diagnostic Clusters	0.054[43]	0.060
Entire Math Diagnostic	0.003	0.136
SAT-Math	0.010	0.117
SAT-Verbal	0.010	0.117
MPEX2 Favorable Pre-	1.08E-5	0.280
MPEX2 Unfavorable Pre-	6.67E-4	0.177
MPEX2 Favorable + Unfavorable Pre-	2.52E-4	0.2795
MPEX2 Favorable Pre-Coherence Cluster	1.325e-05	0.273
MPEX2 Unfavorable Pre-Coherence Cluster	2.53E-4	0.2015
MPEX2 Favorable &Unfavorable Pre-Coherence	1.04E-4	0.3021
MPEX2 Favorable Pre-Concepts Cluster	0.002	0.1456
MPEX2 Unfavorable Pre-Concepts Cluster	0.020	0.08618
MPEX2 Favorable Pre-Independence Cluster	0.002	0.1518
MPEX2 Unfavorable Pre-Independence Cluster	0.004	0.1324
MPEX2 F & U Pre-Coherence + F pre-Concept	4.48E-4	0.2947
MPEX2 F & U Pre-Coherence + F pre-Independence	1.29E-4	0.327
MPEX2 F & U Pre-Coherence + F & U pre-Independence	2.13E-4	0.342

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[43] Note: The math diagnostic clusters is the only indicator failing to be significant at the 0.05 level.

Appendix O: Statistical Results for All Indicators for Post-instruction FMCE Scores

Table 35: Pre-Instruction Indicators for square root of post-instruction FMCE scores

	p-value	R^2
Math Diagnostic Clusters	0.143	0.035
Entire Math Diagnostic	0.010	0.104
SAT-Math	0.006	0.131`
SAT-Verbal	0.033	0.082
MPEX2 Favorable Pre-	4.66E-6	0.297
MPEX2 Unfavorable Pre-	0.003	0.134
MPEX2 Favorable + Unfavorable Pre-	9.57E-5	0.304
MPEX2 Favorable Pre-Coherence Cluster	4.08E-6	0.300
MPEX2 Unfavorable Pre-Coherence Cluster	6.32E-4	0.178
MPEX2 Favorable Pre-Concepts Cluster	1.98E-4	0.208
MPEX2 Unfavorable Pre-Concepts Cluster	0.022	0.085
MPEX2 Favorable Pre-Independence Cluster	0.006	0.118
MPEX2 Unfavorable Pre-Independence Cluster	0.045	0.065

Table 36: Pre-instruction MPEX2 Explanatory Model for square root of post-instruction FMCE scores

	p-value	R^2
MPEX2 F+U Pre-Coherence + F Pre-Concepts+ F Pre-Indepencence	2.51E-4	0.338
MPEX2 F+U Pre-Coherence + F Pre-Concepts	1.42E-4	0.325
MPEX2 Favorable &Unfavorable Pre-Coherence	3.04E-5	0.332

Table 37: Post-instruction Indicators for square root of post-instruction FMCE scores

	p-value	R^2
MPEX2 Favorable Post-	0.003	0.140
MPEX2 Unfavorable Post-	0.010	0.105
MPEX2 F & U Post-	0.027	0.145
MPEX2 Favorable Post-Coherence	9.97E-4	0.166
MPEX2 Unfavorable Post-Coherence	0.002	0.146
MPEX2 Favorable Post-Concepts	0.045	0.065
MPEX2 Unfavorable Post-Concepts	0.052	0.061
MPEX2 Favorable Post-Independence	0.033	0.074
MPEX2 Unfavorable Post-Independence	0.042	0.067

Table 38: Post-instruction MPEX2 Explanatory Model for square root of post-instruction FMCE scores

	p-value	R^2
MPEX2 F+U Post-Coherence	0.006	0.191
MPEX2 F+U Post-Coherence + F Post-Independence	0.015	0.191

Appendix P: Statistical Results for All Indicators for Pre-instruction MPEX2 Scores

Table 39: Indicators for favorable pre-instruction MPEX2 scores

	p-value	R^2
FMCE Pre-	6.24E-6	0.290
Math Diagnostic Clusters	0.044	0.066
Entire Math Diagnostic	0.007	0.115
SAT-Math	0.012	0.111
SAT-Verbal	2.15E-5	0.286

Table 40: Indicators for unfavorable pre-instruction MPEX2 scores

	p-value	R^2
FMCE Pre-	0.001	0.156
Math Diagnostic Clusters	0.644	0.004
Entire Math Diagnostic	0.292	0.018
SAT-Math	0.107	0.047
SAT-Verbal	2.73E-5	0.280

Table 41: Indicators for favorable pre-instruction Coherence scores

	p-value	R^2
FMCE Pre-	9.59E-6	0.281
Math Diagnostic Clusters	0.035	0.072
Entire Math Diagnostic	0.012	0.100
SAT-Math	0.020	0.096
SAT-Verbal	5.27E-4	0.201

Table 42: Indicators for unfavorable pre-instruction Coherence scores

	p-value	R^2
FMCE Pre-	8.85E-4	0.170
Math Diagnostic Clusters	0.086	0.048
Entire Math Diagnostic	0.031	0.075
SAT-Math	0.055	0.066
SAT-Verbal	0.012	0.112

Table 43: Indicators for favorable pre-instruction Concepts scores

	p-value	R^2
FMCE Pre-	0.002	0.150
Math Diagnostic Clusters	0.001	0.159
Entire Math Diagnostic	4.44E-4	0.187
SAT-Math	0.034	0.081
SAT-Verbal	0.045	0.072

Table 44: Indicators for unfavorable pre-instruction Concepts scores

	p-value	R^2
FMCE Pre-	0.028	0.078
Math Diagnostic Clusters	0.127	0.038
Entire Math Diagnostic	0.111	0.041
SAT-Math	0.215	0.028
SAT-Verbal	0.018	0.100

Table 45: Indicators for favorable pre-instruction Independence scores

	p-value	R^2
FMCE Pre-	9.79E-4	0.167
Math Diagnostic Clusters	0.488	0.008
Entire Math Diagnostic	0.216	0.025
SAT-Math	0.176	0.034
SAT-Verbal	1.88E-4	0.229

Table 46: Indicators for favorable pre-instruction Independence scores

	p-value	R^2
FMCE Pre-	0.004	0.130
Math Diagnostic Clusters	0.860	5.21E-4
Entire Math Diagnostic	0.612	0.004
SAT-Math	0.330	0.017
SAT-Verbal	5.76E-4	0.199

Appendix Q: Statistical Results for All Indicators for Post-instruction MPEX2 Scores

Table 47: Indicators for favorable post-instruction MPEX2 scores

	p-value	R^2
FMCE Pre-	0.001	0.159
FMCE Post-	0.001	0.159
FMCE <*g*>	0.003	0.139
Math Diagnostic Clusters	0.132	0.037
Entire Math Diagnostic	0.130	0.038
SAT-Math	0.470	0.010
SAT-Verbal	0.230	0.027

Table 48: Indicators for unfavorable post-instruction MPEX2 scores

	p-value	R^2
FMCE Pre-	0.017	0.091
FMCE Post-	0.020	0.086
FMCE <*g*>	0.074	0.052
Math Diagnostic Clusters	0.544	0.006
Entire Math Diagnostic	0.375	0.013
SAT-Math	0.356	0.016
SAT-Verbal	0.735	0.002

Table 49: Indicators for favorable post-instruction Coherence scores

	p-value	R^2
FMCE Pre-	0.017	0.091
FMCE Post-	0.020	0.086
FMCE <*g*>	0.074	0.052
Math Diagnostic Clusters	0.545	0.006
Entire Math Diagnostic	0.375	0.013
SAT-Math	0.356	0.015
SAT-Verbal	0.735	0.002

Table 50: Indicators for unfavorable post-instruction Coherence scores

	p-value	R^2
FMCE Pre-	0.012	0.101
FMCE Post-	0.004	0.128
FMCE <*g*>	0.013	0.099
Math Diagnostic Clusters	0.412	0.011
Entire Math Diagnostic	0.260	0.021
SAT-Math	0.148	0.038
SAT-Verbal	0.960	4.60E-5

Table 51: Indicators for favorable post-instruction Concepts scores

	p-value	R^2
FMCE Pre-	0.047	0.064
FMCE Post-	0.031	0.076
FMCE <*g*>	0.023	0.083
Math Diagnostic Clusters	0.099	0.045
Entire Math Diagnostic	0.146	0.035
SAT-Math	0.170	0.035
SAT-Verbal	0.092	0.052

Table 52: Indicators for unfavorable post-instruction Concepts scores

	p-value	R^2
FMCE Pre-	0.0356	0.072
FMCE Post-	0.067	0.055
FMCE <*g*>	0.150	0.034
Math Diagnostic Clusters	0.075	0.052
Entire Math Diagnostic	0.060	0.058
SAT-Math	0.120	0.045
SAT-Verbal	0.737	0.002

Table 53: Indicators for unfavorable post-instruction Independence scores

	p-value	R^2
FMCE Pre-	0.013	0.099
FMCE Post-	0.021	0.086
FMCE <*g*>	0.035	0.072
Math Diagnostic Clusters	0.427	0.011
Entire Math Diagnostic	0.385	0.013
SAT-Math	0.981	1.05E-5
SAT-Verbal	0.604	0.005

Table 54: Indicators for unfavorable post-instruction Independencee scores

	p-value	R^2
FMCE Pre-	0.036	0.071
FMCE Post-	0.059	0.058
FMCE <*g*>	0.181	0.030
Math Diagnostic Clusters	0.826	8.08E-4
Entire Math Diagnostic	0.965	3.23E-5
SAT-Math	0.928	1.52E-4
SAT-Verbal	0.719	0.002

Appendix R: Scientific Process Present on the Fundamentals of Land Surveying (FS) Exam

I. Algebra and Trigonometry 11%[44]

(units of measurement; formula development; formula manipulation; solving systems of equations; basic mensuration formulas for length, area, volume; quadratic equations; trigonometric functions; right triangle solutions; oblique triangle solutions; spherical triangle solutions; trigonometric identities)

III. Probability and Statistics, Measurement Analysis, and Data Adjustment 5%

(standard deviation; variance; standard deviation of unit weight; tests of significance; concept of probability and confidence intervals; error ellipses; data distributions and histograms; analysis of error sources; error propagation; control network analysis; blunder trapping and elimination; least squares adjustment; calculation of uncertainty of position; accuracy standards; analysis of historical measurements)

IV. Basic Sciences 4%

(light and wave propagation; basic electricity; optics; gravity; refraction; mechanics; forces; kinematics; temperature and heat; biology; dendrology; geology; plant science)

VII. Written Communication 6%

(written communication; grammar; sentence structure; punctuation; bibliographical referencing)

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[44] These percentages tell the question type's proportion of the entire FS Exam. (NCEES, 2005)

Appendix S: Introductory Physics Topics on the Morning Portion of the Fundamentals of Engineering (FE) Exam

VII. Engineering Mechanics (Statics and Dynamics) 10%[45]

- A. Resultants of force systems
- B. Centroid of area
- C. Concurrent force systems
- D. Equilibrium of rigid bodies
- E. Frames and trusses
- F. Area moments of inertia
- G. Linear motion (e.g., force, mass, acceleration, momentum)
- H. Angular motion (e.g., torque, inertia, acceleration, momentum)
- I. Friction
- J. Mass moments of inertia
- K. Impulse and momentum applied to:
  - 1. particles
  - 2. rigid bodies
- L. Work, energy, and power as applied to:
  - 1. particles
  - 2. rigid bodies

X. Fluid Mechanics 7%

- A. Flow measurement
- B. Fluid properties
- C. Fluid statics
- D. Energy, impulse, and momentum equations
- E. Pipe and other internal flow

XI. Electricity and Magnetism 9%

- A. Charge, energy, current, voltage, power
- B. Work done in moving a charge in an electric field (relationship between voltage and work)
- C. Force between charges
- D. Current and voltage laws (Kirchhoff, Ohm)
- E. Equivalent circuits (series, parallel)
- F. Capacitance and inductance
- G. Reactance and impedance, susceptance and admittance
- H. AC circuits
- I. Basic complex algebra

XII. Thermodynamics 7%

- A. Thermodynamic laws (e.g., 1st Law, 2nd Law)
- B. Energy, heat, and work
- C. Availability and reversibility
- D. Cycles
- E. Ideal gases
- F. Mixture of gases
- G. Phase changes
- H. Heat transfer
- I. Properties of:
  - 1. enthalpy
  - 2. entropy

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[45] These percentages tell the portion of questions each section contributes to the entire morning section of the exam (NCEES, 2005).

Appendix T: Relevant ABET Engineering Technology Program Requirements

Criterion 2. Program Outcomes

An engineering technology program must demonstrate that graduates have:

a. an appropriate mastery of the knowledge, techniques, skills and modern tools of their disciplines,
b. an ability to apply current knowledge and adapt to emerging applications of mathematics, science, engineering and technology,
c. an ability to conduct, analyze and interpret experiments and apply experimental results to improve processes,
d. an ability to apply creativity in the design of systems, components or processes appropriate to program objectives,
e. an ability to function effectively on teams,
f. an ability to identify, analyze and solve technical problems,
g. an ability to communicate effectively,
h. a recognition of the need for, and an ability to engage in lifelong learning,
i. an ability to understand professional, ethical and social responsibilities,
j. a respect for diversity and a knowledge of contemporary professional, societal and global issues, and
k. a commitment to quality, timeliness, and continuous improvement.

Criterion 4. Program Characteristics

Physical and Natural Science

The basic science content can include physics, chemistry, or life and earth sciences that support program objectives. This component must include laboratory experiences, which develop expertise in experimentation, observation, measurement and documentation.

Appendix U: PHY 107 Lecturer's Lab Dilemma

I: What do you see the modeling labs doing?

"On the one hand, there's a lot of conceptual development in the modeling labs, I think students have to really think conceptually. I'm not sure that this group of students has the ability to deal with it. Some of them do, don't misunderstand me. When I talk about the group as a whole I'm thinking of the avg. student not the best or the worst. I don't. I think it would be hard for them. I think it would stress them out a lot. And I'm not sure the lab itself would be very productive as a result. And there's also the possibility that year after year things would just get passed down, "This is what you have to do ahahah" type of thing and I'm not sure it would really be beneficial for them.

Secondly, conceptual understanding of all the physics would be great for everybody that takes a physics course. I think that's very high hopes, and I think it's not a practical expectation inside every physics class. I think that the conceptual labs, the modeling labs are great with regards to conceptual development, but I don't believe that my group of students needs as deep a conceptual understanding as I think the modeling labs require. Now, there are activities like whiteboarding and stuff, a few other activities, making presentations in front of your peers, and things like that. That modeling as I understand it has in them, that I would like to implement into my class, but my difficulty is I'd have to get myself. This another question of, well if I try to introduce whiteboarding, as an example, I have to shorten the lab because I have to have time to not only make the presentation for everybody if there's 6 groups. They also have to have time to do their calculations. So then there's the question of doing what has been done in both 121 & 111, do I make some of the labs 2 week labs where they do some stuff and then doing something else the following week. Well, then I think I'd have to go back to having 14 weeks of lab. It isn't more important for me to have the students be exposed to a lot of varying, being engineering/engineering technology people is it better for me to have them be exposed to a lot of different lab equipment where they're measuring different things or is it better for me to give them a better conceptual understanding. I'm not convinced that the labs help everyone who takes them get a deeper conceptual understanding. I think the tutorials do a better job on that then the labs do. I look upon the labs as applications, and there may be some conceptual development in them, which I hope happens in the circuits lab. Sometimes yes, sometimes no, but overall I don't think the modeling labs would do that with my group of students."

Appendix V: Interviewed Student Data

Table 55: Overall Data for All Students Interviewed

	Major	Math/Context Bin[46]	Overall Math Diagnostic	FMCE Pre-	FMCE Post-	FMCE $<g>$[47]	MPEX2 Pre-	MPEX2 Post-
PHY 107 mean			46±19 (s.d.)	19±15	28±24	0.14± 0.24	46/32	40/36
Student #1	CMT	low-high	40	49	55	0.12	61/26	42/39
Student #2	EET	mid-mid	29	18	39	0.26	48/26	42/36
Student #3	CMT	mid-high	45	15	18	0.04	55/29	68/10
Student #4	EET	high-mid	58	15	12	-0.04	32/42	22/55
Student #5	CMT	mid-mid	32	9	9	0.00	29/39	23/58
Student #6	CMT	mid-low	40	6	9	0.03	48/22	13/42

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[46] The class was split into high-mid-low bins based upon the math diagnostic *clusters* and high-mid-low based on a physics question. The category going across is read math diagnistic bin-physics question bin.

[47] The mean normalized gain here is the mean of individual student normalized gains, whereas the scoring template gives the normalized gain of the pre-/post- class means.

Table 56: MPEX2 Comparison of Students Interviewed

%F/%U	Major	Overall	Coh	Conc	Ind	Coh-Math	Coh-Real	Ind-Epist	Ind-Pers
SET Students Pre-		46/32	49/29	24/46	52/31	36/36	65/12	45/35	73/11
SET Students Post-		40/36	42/30	29/46	40/37	36/39	55/19	34/40	57/22
Student #1 Pre=	CMT	61/26	75/8	25/50	75/17	33/33	0/100	63/25	100/0
Student #1 Post-		42/39	33/33	13/63	67/25	33/33	25/50	75/13	33/67
Student #2 Pre=	EET	48/26	50/25	13/38	58/25	67/33	0/50	50/38	67/0
Student #2 Post-		36/32	42/25	13/63	33/25	67/33	0/75	25/25	67/33
Student #3 Pre=	CMT	55/29	58/33	38/25	50/33	33/33	0/100	50/38	67/0
Student #3 Post-		68/10	83/0	63/13	58/17	100/0	0/75	38/25	100/0
Student #4 Pre=	EET	32/42	25/33	0/63	50/33	0/33	0/50	38/50	67/0
Student #4 Post-		23/55	17/58	13/63	25/50	0/67	25/50	25/63	33/0
Student #5 Pre=	CMT	29/39	25/0	0/75	42/33	0/67	0/25	38/38	67/0
Student #5 Post-		23/58	17/50	13/75	42/50	0/33	75/0	25/63	100/0
Student #6 Pre=	CMT	48/23	33/17	63/13	50/33	33/33	0/25	63/25	33/67
Student #6 Post-		13/42	8/58	0/63	17/33	0/100	0/25	13/25	33/33

BIOGRAPHY OF AUTHOR

Daniel Reed was born in Lewiston, Maine on April 3, 1981. To culminate growing up in Mechanic Falls, Maine, Dan graduated from Edward Little High School in 1999. He then attended Worcester Polytechnic Institute, leaving with a Mechanical Engineering degree in 2003. Following two years in the construction and construction management business, he found that the pleasures of helping people learn to row far exceeded that of meeting deadlines and producing products. With his wife Natalie beginning clinical rotations, they returned to Maine, where Dan entered the Master of Science in Teaching graduate program at The University of Maine in the fall of 2005.

After receiving his degree, Dan will be taking on the responsibility of fatherhood and teaching his daughter Julia in the years to come. If time permits, he may be found gliding over the water in Austin, while most of the world continues to dream of anything but the siren of their alarm clocks. Dan is a candidate for the Master of Science degree in Teaching from The University of Maine in August, 2007.

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