

ADVANCED ENGINEERING TUTORIALS
IN COLLEGE PHYSICS

by

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ABSTRACT

Physics education research has shown that physics students fail to understand basic Newtonian mechanics after completing physics courses, irrespective of the proficiency of the teacher or reputation of the institution when using traditional lecture formats. Further research has shown that inquiry based tutorial methods result in greater conceptual understanding by students. Additionally, tutorial methods have been shown to also improve student attitudes and motivations about physics.

Problem solving has long been notoriously difficult to teach. Through the use of tutorials, many students learn physics concepts more intuitively. Often referred to as interactive engagement, or inquiry methods, tutorials help the students teach themselves about the science involved in physical phenomena.

Using engineering principles to teach physics promises to add to the efforts of physics education research. Symbolic problem solutions allow the students to understand the relationship between the variables in the physical system, and the affects they have. Graphical analysis helps the students visualize the problems, the interactions involved, and the solutions meaning. Optimization, either using calculus techniques, or qualitative analysis of advantages and disadvantages, allow the student to see the behavior of the system when tailored to fit design constraints.

The tutorials used in this study were designed to incrementally build an intuitive understanding of engineering components such as capacitors, solenoids, achromatic lenses, structures, or dynamic systems. Each step was built on the previous problem to show a logical progression. Tutorials were developed symbolically. Study of the symbolic formula helped the student answer conceptual questions about the system. Solutions were finally solved quantitatively using realistic numbers to show true orders of magnitude. Symbolic equations were then analyzed for optimization through calculus or qualitative means. Sometimes multiple solutions were possible and creativity was necessary.

INTRODUCTION AND BACKGROUND

"Physics! That was my worst subject. You must be so smart to understand it!" recounted Randall Knight (2002, p. iii) of the many times people have responded in that way when they learn that he is a physics teacher. It is also a response that, while an ego boost at first, became more disagreeable with repetition. Physics is a rich science with so many awe-inspiring aspects. How the world around us works, how we interact with it, advancements in technology, and news stories about groundbreaking discoveries are all encompassed by physics. Yet generations of students have left the classroom with a bad experience with physics education. As a teacher of physics, I worried that some of my students were going to be added to the rolls of those who view physics as a subject that was impossible to understand.

As an adjunct professor at Sheridan College in Sheridan, Wyoming, I taught physics, engineering, and math. Teaching engineering and math is challenging, but teaching General and College Physics I & II was unlike any of my other courses. There seemed to be too much material to cover. What I did cover from the 1600-page textbook didn't seem to sink in. Even constant reviewing didn't help most students who still seemed to be missing fundamental questions.

It was in this context that I discovered the field of physics education research and realized that physics teachers much more highly qualified than I have been struggling with these same difficulties. Through over twenty years of physics education research, progress has been made in discovering simple techniques not only to increase the

students' understanding of the material, but also to increase their enjoyment of learning physics (Knight, 2002).

This research was conducted at Sheridan College, a community college in the town of Sheridan in northeastern Wyoming. Sheridan is the county seat of Sheridan County with a population of over 17,000 in the city and over 29,000 in the county (Wikipedia, 2015). Main industries in the area include agriculture, tourism, education, energy extraction, government, and health care. Wyoming has a population of 580,000, making it the least populous state and is often referred to as a “small town with really long streets.”

Sheridan College is part of the Northern Wyoming Community College District which serves three counties through campuses in Sheridan and Gillette, with outreach centers in Buffalo, Kaycee, and Wright. Sheridan College offers associate degrees and certificate programs, and prepares students for transfer to four-year colleges. The college serves over 4,000 students, and nearly 1,500 of those attend full time (NWCCD, 2015).

I taught engineering, physics, and math courses as an adjunct at Sheridan College. My students were primarily first and second-year engineering students preparing for transfer to other four-year schools, such as the University of Wyoming or Montana State University. However, the physics classes also included students in medical programs and other technical fields who are in need of advanced science electives.

The physics courses were technically two classes each semester: a calculus-based physics course for engineers and a trigonometry-based course for the other college tracks.

I had found that the best approach for teaching was to use a calculus-based text as the foundation for the course. I taught the concepts of calculus to all the students using graphical methods that illustrate that calculus functions were solvable by geometry when restricted to second-order equations. This technique was not only understandable for the trigonometry students, but also helped the calculus students to better understand calculus in its applications. The Physics I course covered classical mechanics and thermodynamics. The Physics II course covered electromagnetism and optics.

In teaching engineering, physics, and math at the college level, I had several overarching teaching goals that I felt got to the heart of the purpose of education. Most importantly, I wanted to instill a sense of wonder for the sciences in the students' minds. I find the world to be a fascinating combination of simplistic elegance and unimaginable complexity. There is no limit to the learning one can accomplish in this lifetime, and I wanted the students to pursue that in whatever fashion their passions direct. By tying the course material to the truly fascinating aspects of technology and science, their interest in learning could be piqued and students could be inspired to be active participants in expanding their knowledge.

I also wanted to challenge the students to be proficient problem solvers. After completing my degree in mechanical engineering, I would often describe it to others as not so much technical job training, but rather a degree in problem solving. The ability to reason through problems, either academic or personal, was a critical skill to learn. It is a virtue to see difficulties as opportunities to challenge skills and intellect, not as

impediments that hold us back. Problem solving in physics teaches the use of logic, reason, and analytical thinking that is fundamental to that goal.

While teaching physics, I was constantly frustrated by the material included in the textbook. The textbooks spent too much time deriving complex equations, and then simply plugging in numbers from example problems, many of which consisted of highly unrealistic quantities. The resulting numeric answer might as well have been a set of winning lottery ticket numbers since they had no inherent meaning to the student, and no context outside of being "the right answer." As an engineer, more of my focus had always been on understanding a few underlying principles and the equations that represented them, and applying them in general to the problem at hand. After determining the specific equation relationship for my problem, understanding the impact of each variable and how it affected the outcome was crucial to determining the optimum solution to the problem.

More specifically, I felt that physics should be taught as a set of more fundamental principles, which the students would then learn to understand and apply to generalize problems. After determining the generalized solution, the relationships and interplay between the variables was analyzed to find the optimum solution. Developing these skills also requires a more deliberate progression of problems for students to solve, instead of the grab-bag approach of assigning a dozen problems from over a hundred available problems which have little connection to each other.

As I developed my ideas for how I would like to teach physics from my engineering perspective, I found that my vision lined up with many of the same conclusions at which physics education research had been arriving. I felt that an engineering perspective on physics was critical to my teaching method, and I wanted my students to also gain these insights into physics in such a way that the concepts are more intuitive and their understanding is more complete than just being able to find the right solution for a problem that has only one right answer.

To accomplish this end, I have drafted advanced engineering tutorials that utilize symbolic solutions, graphical analysis, and design optimization for use as teaching materials in my physics classes. The purpose of my study was to test the effectiveness of the use of advanced engineering tutorials that include symbolic representation, graphical analysis, design, optimization, construction, and application in increasing my physics students' conceptual physics understanding, problem-solving skills, and enjoyment of learning physics.

CONCEPTUAL FRAMEWORK

At the heart of the problem with introductory physics education is that the basic principles themselves are simple, but the effects of those principles are often counter-intuitive, and their applications are numerous. Trying to put this in perspective (with some physics humor involving special relativity-length contraction - called Lorentz contraction), Arons (1979) wrote:

It is the basic premise of the vast majority of introductory physics courses taught currently that, if one takes a huge breadth of subject matter and

passes it before the students at sufficiently high velocity, the Lorentz contraction will shorten it to the point at which it drops into the hole which is the student mind. In such courses, final grades, which are invariably adjusted to allow "passing" of a reasonable fraction of the students, cannot possibly be an index of the kind of intellectual development and achievement to which most of us render lip service. (p. 650)

Beginning with the work of Arons in the 1970s, the methodology of physics education has evolved from traditional lecture-based modes to more modern models of education. The outgrowth of physics education research (PER) has made a substantial contribution to education in many fields and has validated the essential use of metacognition in problem solving, constructivist theories of learning, conceptual change models, and tutorial instruction. Metacognition focuses on understanding one's own thinking or problem-solving process. Constructivist approaches to learning are student-centered teaching methods that utilize scaffolding methods to build upon students' current knowledge and understanding. Conceptual change models focus on addressing students' overarching understanding of fundamental concepts. Tutorial instruction involves more interactive approaches to learning that involve significant feedback during the learning process (Knight, 2002).

The first area of concentration by PER was in teaching the art of problem solving. Heller and Reif (1982) attempted to lay out a prescriptive approach to problem solving. Their basic systematic approach was broken into three stages, "(a) the generation of an initial problem solution; (b) the actual construction of the solution, including procedures for making judicious decisions facilitating search; and (c) the subsequent assessment and improvement of the solution" (p. 4-5).

On this cognitive foundation, the researchers employed subject-specific knowledge, such as kinematic formulas, to build the actual solutions. Also included in this prescriptive system is a feedback loop, wherein the students assess their own solutions to learn how to improve their techniques in future applications. Their follow-up paper, (Heller & Reif, 1982) verified their prescriptive model, as evidenced by the fact that groups of physics students instructed to use their systematic approach were more successful than physics students who were allowed to solve the problems free-form.

As progress was made in developing students cognitive skills in introductory physics classes, it was noted that cognitive problem solving skills were not sufficient to develop a comprehensive understanding of physics. While students could perform problem solving tasks and pass the course, very few could correctly identify the underlying concepts involved in the problem (Redish, 1994). In order to more fully ensure that students understood the material and concepts involved, student preconceptions and misconceptions had to be specifically addressed and corrected. The method used a technique of building on each student's foundation of knowledge instead of presenting topics in isolation. This helped lead to a change in focus for PER from cognitive problem solving to conceptual understanding (Redish & Steinburg, 1999).

To help evaluate the conceptual understanding that students should have after completing a physics course, many conceptual surveys were developed in the 1990's. The most widely used has been the Force Concept Inventory (FCI) which focuses on basic applications of Newton's Laws of Motion as the core of an introductory mechanics

course in physics (Hestenes, Wells, & Swackhamer, 1992). This test focuses on specific preconceptions or misconceptions among physics students that were an impediment to learning. The FCI is most often given in a pre/post-test format, in which the students are given the test at the beginning of the course to measure their current understanding of the topics, and then again after the course to measure the improvement the course material has made in their learning. Concept tests such as the FCI are most often used as course evaluation tools, and credit is only given for test completion (Hestenes & Halloun, 1995).

In a comprehensive review of physics courses throughout the country, FCI data was collected from 62 introductory physics courses which contained data for over 6,000 students. These courses included various teaching methods categorized as either traditional lecture-based courses or interactive engagement methods. Interactive engagement methods are defined as those methods that emphasize conceptual understanding through highly interactive activities which give the students immediate feedback through discussion with peers and instructors. To evaluate students' physics learning, the FCI test results were gathered in a pre/post-test format. This research demonstrated that the greatest improvements were from classes that used interactive engagement teaching methods. It also revealed that traditional teaching formats yielded similarly low gains across a wide variety of traditional teaching styles. There was little difference in class results even when taught by the most talented and popular instructors, or even for classes at prestigious universities and technical institutions (Hake, 1998).

As another tool for improving learning, engineering is being used as an integral part of science instruction. Engineering is the creative application of science and mathematics to design or develop technology that serves useful purposes. Engineering is beginning to be viewed as such an integral part of teaching science that the Next Generation Science Standards have linked science and engineering practices into a single set of objectives for science instruction. The Next Generation Science Standards Framework states:

In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. (National Research Council Framework, 2012, p. 68-69)

For introductory physics classes, using engineering as a tool to teach the science of physics can be beneficial in that the scientific phenomena being studied are experienced in everyday life and used in ordinary technology accessible by nearly all students (NGSS Lead States, 2013).

Many engineering courses employ design projects to give students experience in application of course knowledge. This approach has been applied to physics courses tailored to engineering students as project-based learning in which students work on larger, realistic problem scenarios that integrate a variety of course competencies simultaneously. The underlying mechanism of how engineering may improve physics

teaching lies in the deeper understanding involved in manipulating physics to achieve a desired outcome (Bowe, Flynn, Howard, & Daly, 2003).

Oliver and Kane (2011) discussed the effects of incorporating engineering design modules in physics classes. Of note, the engineering methodologies were found to be of most benefit to the lowest scoring students, as well as specific hard-to-reach demographics, such as women and minorities. Given these positive results, it is a surprising fact that “many physics instructors do not incorporate the findings of physics education research into practice. Specifically, student design is one of the least used reform-based physics pedagogies” (p. 242). The open-ended nature of design that allows for a range of possible solutions helps solidify the fundamental conceptual knowledge needed to analyze the problem, versus traditional “plug-and-chug” problem-solving techniques. Often, there are multiple solutions for engineering problems. Being able to experiment with the interaction between multiple variables, weigh the ramifications of design choices, and choose the particular design solution that optimizes the solution based on engineering constraints, promises to give the student the most comprehensive physics understanding of all physics education teaching methods.

A core feature of an engineering approach is the heavy reliance on symbolic solutions and reasoning for most aspects of the course. Engineers regularly utilize custom equations that are very specific and specialized, but are maintained in symbolic form to allow for optimization at final application. While it has been shown that the symbolic form of equations can be difficult for students to adapt to, this appears to vary

in effect for different topics or problem types within the physics coursework (Torigoe & Gladding, 2007). Overall, the experience gained in symbolic solutions and reasoning allows the students to better understand the derivations of the basic physics equations, and prepares the students for further understanding when applying formulas to engineering design or optimization problems.

Graphical analysis has been relied upon for tutorial work in interactive engagement courses (McDermott & Saffer, 2002). Particularly for kinematics, a graphical approach to the application of calculus in physics problems is superior to strict mathematical formulations (Knight, 2016). Many areas of the physics curriculum could benefit from increased emphasis on graphical representations and models. Close, Close, and Donnelly (2012), have shown that well-crafted graphical representation can increase learning efficiencies. While a study by Khan, Hu, Nyugen, and Rebello (2011) showed that symbolic problem sets were easier for students to solve versus graphical presentations of the same problem, a physics curriculum need not limit itself to one model or another, and the use of both could be complementary.

On the foundation of symbolic reasoning and graphical analysis, the work of design optimization can be built. Inherent in the use of symbolic solutions is the ability to easily recognize the effect of each variable on the system. Recognizing the variable involved allows the student to see if the proportions are directly or inversely proportional, and if the relationship is linear or exponential. There is great opportunity here to relate the history of the early pioneers of science such as Kepler, Galileo and Newton, whose

formulations were expressed as proportions, not equations, since the ability and accuracy needed for measuring the universal constants were not achievable at that time. Focusing the student on how the symbolic formula is not applied in order to achieve a single numerical answer, but instead states how a physical phenomenon behaves under varying conditions, is the key to teaching physics. As noted by Sherin (2001):

successful physics students learn to express a moderately large vocabulary of simple ideas in equations and to read these same ideas out of equations. I call the elements of this vocabulary symbolic forms. Each symbolic form associates a simple conceptual schema with an arrangement of symbols in an equation. Because they possess these symbolic forms, students can take a conceptual understanding of some physical situation and express that understanding in an equation. Furthermore, they can look at an equation and understand it as a particular description of a physical system. (p. 482)

In designing a new physics course for engineering, McKagan, Perkins, and Wieman (2006) included the explicit applications of physics in technology for each section the course. Particularly at the introductory level, physics is best understood in its useful application in engineering and technology. The subtleties in design, material selection, and specific geometries yield great insight into the underlying physics. This incorporates a much more realistic and authentic educational experience while still preserving the academically intensive nature of a problem. A physics-only problem may use convenient numbers that have little basis in reality, such as a mechanics problem in a common university physics textbook involving a 1.1-pound arrow being shot from a bow by a hunter (Serway, 2014). Real arrows weigh less than two ounces. Engineering-based problems look at actual commercially available supplies, such as resistors of only certain

ratings or springs of certain spring constants, which students could actually obtain to verify solutions (Oliver & Kane, 2011). Also, real-world limitations involving friction, heat, voltage loss, etc., help the students differentiate between the theory and actual applications of the theory.

Also related to the design approach of engineering is a deliberate problem progression used by engineering-based material which allows the students to see the logical progression of conceptual ideas that are used to solve problems of increasing complexity. With each successive problem carefully building upon the last, the intricacies of the application of each physics principle is more clearly understood by the student. “This is necessary in order that students perceive physics as an integrated whole rather than as a collection of independent parts” (Bowe, Flynn, Howard, & Daly, 2003, p. 743).

Ultimately, an ideal physics curriculum should include methods from all three problem-solving areas: cognitive problem solving, conceptual understanding, and engineering design. Having a robust and rigorous method for solving physics problems gives students the ability to work even when unfamiliar with the material. The conceptual understanding of physics will give students an intuitive knowledge of the science that will outlast the memorization of formulas. And finally, engineering design experience should be utilized to give a much more authentic, valid, and comprehensive experience with physics education.

METHODOLOGY

In order to test the use of an engineering approach for enhancing physics education, research was conducted using draft physics tutorials designed to incorporate engineering principles. This research was conducted during the 2015-16 academic year at Sheridan College. The courses studied included both calculus and trigonometry based physics courses, which are taught simultaneously in a single class. The calculus based courses were College Physics I & II and the trigonometry based courses were General Physics I &. The Fall 2015 course studied was Physics II, which included students enrolled in both General Physics II and College Physics II classes, and covered the topics of electricity, magnetism, and optics. The Spring 2016 course studied was Physics I, which included both General Physics I and College Physics I classes, and covered topics in kinematics, Newtonian mechanics, energy, oscillatory motion, and thermodynamics. The research methodology for this project received an exemption by Montana State University's Institutional Review Board, and compliance for working with human subjects was maintained (Appendix A).

The Physics II class included seven students: two enrolled in the trigonometry-based course and five enrolled in the calculus-based course. The Physics I class included three students enrolled in the trigonometry-based course and four enrolled in the calculus-based course. The textbook used was Sears and Zemansky's *University Physics with Modern Physics*, 14th edition by Young and Freedman, published by Pearson (2015).

To test the efficacy of the engineering tutorials, the course was first taught primarily as a standard lecture-format class. The lectures were more interactive and conceptual than traditional lecture-based courses, but not quite as interactive and student-centered as most inquiry-based instruction. The students were asked many questions, and they were also challenged to explain, predict, and debate outcomes throughout the lecture. The coursework closely followed the textbook, and problems were selected from the end-of-chapter assignments in the book as well, administered through Pearson's Mastering Physics online learning management system. Section tests were given every four to five weeks covering main topics of the material. This served as the non-treatment phase of the project.

At the end of the main section of the course and before exposure to the engineering tutorials, the students were given conceptual survey instruments to assess the conceptual understanding they had gained from the basic lecture class thus far. The students were informed that the test scores would not be incorporated into their grade, but that their participation would simply count towards the participation portion of the course grade as outlined in the course syllabus. These conceptual tests were designed by the physics education research community and represented the intuitive understanding of physics that students should have after completing introductory physics courses. These were multiple-choice exams given closed-book and closed-note. Calculations were not necessary, and each problem could be solved in a short period of time.

In the Physics I course, students were administered the Force Concept Inventory (FCI) (Hestenes et.al., 1995). The FCI was comprised of 30 multiple choice questions, and the test takes approximately 30-40 minutes to complete. It focused on the conceptual application of Newton's laws of motion (Figure 1). This test was given as a pre-test before the course began, since some students may have come into an introductory physics course with a solid grasp of Newtonian mechanics already.

- A stone dropped from the roof of a single story building to the surface of the earth:
- (A) reaches a maximum speed quite soon after release and then falls at a constant speed thereafter.
 - (B) speeds up as it falls because the gravitational attraction gets considerably stronger as the stone gets closer to the earth.
 - (C) speeds up because of an almost constant force of gravity acting upon it.
 - (D) falls because of the natural tendency of all objects to rest on the surface of the earth.
 - (E) falls because of the combined effects of the force of gravity pushing it downward and the force of the air pushing it downward.

Figure 1. FCI conceptual question example.

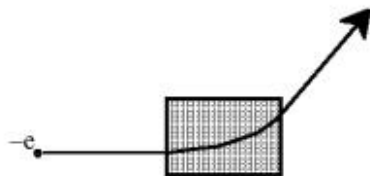
After the lecture portion of the course, the FCI was administered again to obtain a reference score before presentation of the engineering tutorials. After the tutorials, the post-treatment tests were given at the beginning of the final exam period, then the students began work on their traditionally written final exam for the remainder of the final exam period.

To analyze the results of the FCI for Physics I, raw scores were calculated for the three student tests. The pre-course test and the pre-treatment test scores were used to determine a normalized gain score (Hake, 1998a) which represents the fraction of

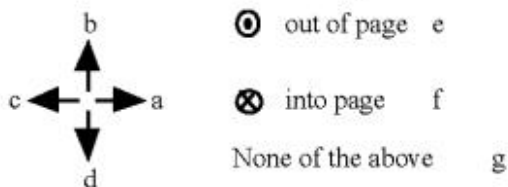
possible improvement a student made before the treatment phase. The student's post-treatment test score was then used to determine a normalized gain score again; this represented the treatment gain.

In Physics II, the students were assessed with the Brief Electricity and Magnetism Assessment (BEMA) (Ding, Chabay, Sherwood, & Beichner, 2006). The BEMA was a 31-question multiple choice test which requires approximately 40-50 minutes to complete. It requires detailed knowledge of electricity and magnetism, but did not require calculations (Figure 2). Since the BEMA required more knowledge specific to an introductory physics course that is not generally common knowledge, the BEMA can be utilized as a course post-test without the pre-test having been administered. However, in this experiment, the test was administered pre-treatment as a means of obtaining a non-treatment score, the same as done with the FCI. The post-treatment tests were given at the beginning of the final exam period, then the students began work on their traditionally written final exam for the remainder of the final exam period.

A moving electron with charge $-e$ travels along the path shown, and passes through a region of electric field. There are no other charges present. The electric field is zero everywhere except in the gray region.



Choose from the following possible directions to answer the question below:



What is a possible direction (a-g) of the electric field in the region where the field is non-zero?

Figure 2. BEMA conceptual question example.

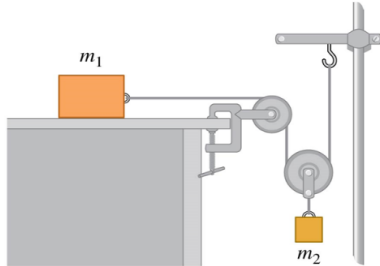
To analyze the results of the BEMA for Physics II, raw scores were calculated for the two student tests. The pre-treatment test and the post-treatment test scores were used to determine a normalized gain score (Hake, 1998a) which represents the fraction of possible improvement a student made above the pre-treatment score on the post-treatment score.

The treatment phase of this study was the final review section of the course in the week before the final exam. The first parts of the engineering tutorials were assigned as homework before beginning the review week (Appendices B & C). The tutorials were developed by expanding them in-class with other exercises inspired by other PER-based material such as *Tutorials in Introductory Physics* (McDermott & Shaffer, 2003) and *Physics For Scientist and Engineers: A Strategic Approach* (Knight, 2016), as well as discussions involving physics use in engineering that has not been developed into written

tutorials yet. The tutorials and in-class discussions were designed for intuitive understanding by building on previous problems to show a logical progression.

Critical to the tutorials was the use of graphical illustrations that were modeled symbolically. The tutorials were completed almost entirely symbolically, where study of the formula can help the student answer conceptual questions about the system (Figures 3 & 4). Solutions may be solved quantitatively using realistic numbers to show true orders of magnitude for realistic applications. From simple principles, the tutorials follow a deliberate problem progression leading to more complex problems, leading to an understanding of engineering components, such as capacitors, solenoids, achromatic lenses, structures, or dynamic systems. Each step builds on the previous problem to show a logical progression. Design and optimization questions were analyzed with calculus or qualitatively to achieve a desired outcome. Sometimes multiple solutions were possible, and creativity was necessary. Finally, real-world applications were described to the student to relate the physics principles to actual technologies.

Traditional Approach (Substitute numbers while deriving answer):



Block m_1 has a mass of 3 kg, and m_2 has a mass of 5 kg.

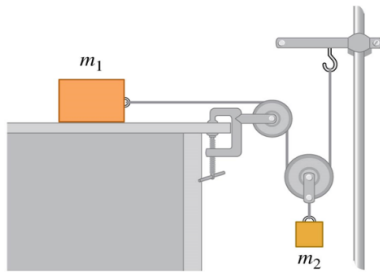
-Find the acceleration of m_1 and m_2 .

$$\begin{aligned}
 F_2 &= m_2 a_2 & F_1 &= m_1 a_1 \\
 2T - m_2 g &= m_2 a_2 & T &= m_1 a_1 \\
 a_1 &= -2a_2 & & \\
 2T - 5(9.81) &= 5a_2 & T &= 3a_1 \\
 2(3a_1) - 49.1 &= 5a_2 & & \\
 6a_1 - 49.1 &= 5a_2 & & \\
 6(-2a_2) - 49.1 &= 5a_2 & & \\
 -12a_2 - 49.1 &= 5a_2 & & \\
 a_2 &= 49.1/(-17) & a_1 &= -2(-2.98) \\
 a_2 &= -2.89 \text{ m/s} & a_1 &= 5.78 \text{ m/s}
 \end{aligned}$$

Student Thoughts: I sure hope those numbers are right. I better check the back of the book and see if I got the right answers...

Figure 3. Traditional textbook physics problem example.

Symbolic (Derive equation of motion fully symbolically):



For the system shown above:

- Find the equations of motion of m_1 and m_2 .
- Explain the significance.
- Determine the accelerations in terms of g for each block if m_1 has a mass of 3 kg, and m_2 has a mass of 5 kg.
- Determine the limits of the accelerations for the cases of $m_1 \gg m_2$ and $m_1 \ll m_2$.

$$\begin{aligned}
 F_2 &= m_2 a_2 & F_1 &= m_1 a_1 \\
 2T - m_2 g &= m_2 a_2 & T &= m_1 a_1 \\
 2m_1 a_1 - m_2 g &= m_2 a_2 & a_1 &= -2a_2 \\
 2m_1(-2)a_2 - m_2 g &= m_2 a_2 & & \\
 -4m_1 a_2 - m_2 g &= m_2 a_2 & & \\
 a_2(-4m_1 - m_2) &= m_2 g & & \\
 a_2 &= \frac{-m_2 g}{4m_1 + m_2} & a_1 &= 2 \frac{m_2 g}{4m_1 + m_2}
 \end{aligned}$$

Newton's equation of motion can be described as $a=F/m$. The driving force of the system is the weight of the hanging mass, $m_2 g$. The inertial components of the system include both m_1 and m_2 , but m_1 contributes not only double, due the mechanical constraint of the motion produced by the pulley system ($a_1 = -2a_2$), but quadruple, additionally due to the mechanical disadvantage of m_2 being resisted by the two cord tension forces, where the cord tension is produced by m_1 's inertia.

$$\begin{aligned}
 a_2 &= \frac{-m_2 g}{4m_1 + m_2} & a_1 &= 2 \frac{m_2 g}{4m_1 + m_2} \\
 a_2 &= \frac{-5g}{4(3)+5} & a_1 &= 2 \frac{5g}{4(3)+5} \\
 a_2 &= \frac{-5}{17} g \approx 0.29g & a_1 &= \frac{10}{17} g \approx 0.58g
 \end{aligned}$$

For $m_1 \gg m_2$, a_1 and a_2 will approach 0.

For $m_1 \ll m_2$, a_2 will approach g , and a_1 will approach $2g$.

Figure 4. Symbolic conceptual physics problem example.

After completion of the tutorials, the class reviewed and discussed the tutorial material in class throughout the week. Further progressions of engineering problems, optimization questions, real-world construction, and applications were discussed in class. Particular attention was paid to the counterintuitive aspects of the physics phenomena. The tutorials were primarily used as a basic worksheet to facilitate in-class discussion on the implications of the physics principles as they are utilized in technological application. This week of tutorials and engineering focuses discussion completed the final week of class, afterwards the post-treatment conceptual test was given, and then the final exam.

Finally, upon completion of the student's final, an engineering tutorial feedback survey was given to the students to gauge the effectiveness of the engineering tutorials (Appendix D). The surveys were optional, however, surveys were received from every student. The surveys were 5-point Likert scales for statements relating to the student's perception of the engineering tutorials concerning various aspects, allowing the students to select *strongly agree*, *agree*, *neutral*, *disagree*, and *strongly disagree* for each item. There was also a prompt for additional comments at the end of the survey. The survey data was analyzed with a Likert chart to discern patterns in student responses for each area of focus of the tutorial. The percentage of items marked as *strongly agree* or *agree* were calculated as the student's positive feedback percentage.

Additionally, college course evaluations had been taken by the school near the end of the semester (Appendix E). The evaluations asked the student if they *strongly agree*, *agree*, *disagree*, and *strongly disagree*, with various statements about the quality

of instruction. The responses are assigned a range of points, from 4 for *strongly agree*, to 1 for *strongly disagree*. The overall number of *strongly agree*, and *agree* statements versus the total number of questions were used to determine the percentage of positive comments to rank the overall feedback quantitatively. There were also several written-response questions on the evaluation to collect student comments. The student responses are averaged for each question, and an overall course average rating is also computed.

Multiple sources of data were collected to analyze the effectiveness of the engineering tutorials in addressing the research questions (Table 1). The conceptual tests were the primary sources for measuring the increase in student's conceptual physics knowledge. More traditional physics problem-solving ability was investigated primarily using the students' performances on tests and exams, as well as overall coursework. The engineering tutorial feedback surveys were the primary source of data for gauging the students' enjoyment of learning physics with this method. The surveys were also used to gauge the students' impressions of the effectiveness of the engineering tutorials on their own conceptual knowledge and problem-solving ability.

Table 1
Data Triangulation Matrix

Research Questions	Source 1	Source 2	Source 3
Can engineering tutorials increase student's conceptual physics knowledge?	Instructor observation	Conceptual assessment tests	Engineering tutorial surveys
Can engineering tutorials improve student's problem solving ability?	Instructor observation	Overall coursework	Engineering tutorial surveys
Can engineering tutorials enhance student's enjoyment of physics?	Instructor observation	College course evaluations	Engineering tutorial surveys

DATA AND ANALYSIS

The conceptual test results for each class were calculated using the students' scores. For the Physics I class, the treatment normalized gain on the Force Concept Inventory (FCI) for the engineering tutorials was 0.22, and the total normalized gain for the course was 0.38 ($N=7$). For the Physics II class, the treatment normalized gain on the Brief Electricity and Magnetism Assessment (BEMA) was 0.09 ($N=7$) (Table 2).

Table 2

Physics Conceptual Test Averages and Normalized Gain

Course	Course Pre-test	Pre-treatment Test	Pre-treatment Gain	Post-treatment Test	Treatment Gain	Total Gain (Value)
Physics I FCI	37.1%	50.0%	0.20	61.0%	0.22	0.38 (Medium)
Physics II BEMA	-	31.3%	-	37.3%	0.09	0.09 (Low)

The Physics I students' FCI results were analyzed and compared with national averages (Von Korff et al., 2016). The pre-course test average score was 37%. The pre-treatment test average score was 50% which represented a normalized gain of 20%. These results were compared to national post-course test scores and gains. The post-treatment average test score was 61%, which represented a normalized gain of 38%. These were again compared with national post-course test scores and gains (Figure 5).

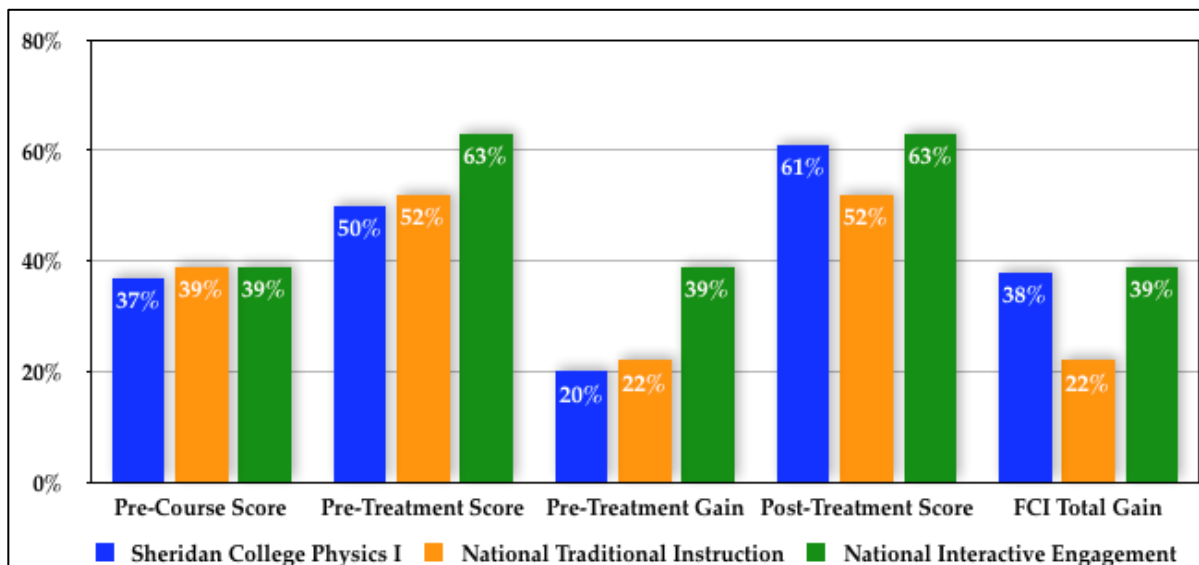


Figure 5. FCI scores and normalized gain for Physics I, ($N=7$).

The Physics II students' BEMA results were analyzed and compared with national averages (PhysPort Assessments, 2016). The pre-treatment test average score was 31%, which was compared with national pre-course tests ($N=7$). The post-treatment average test score was 37%, which represented a normalized gain of 9%. This was compared with national post-course tests (Figure 6).

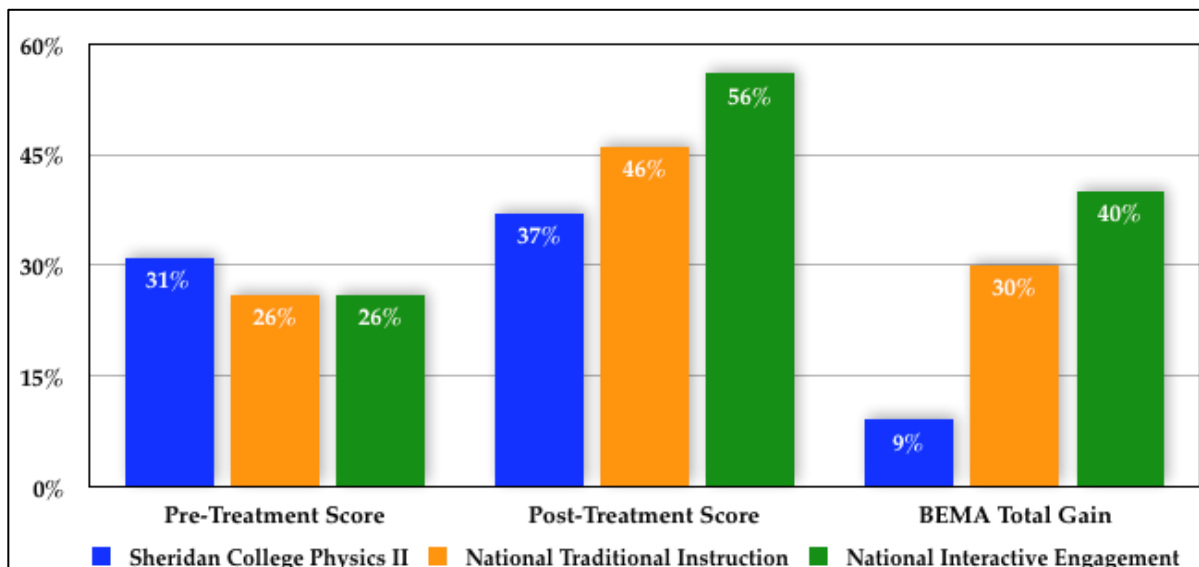


Figure 6. BEMA scores and gain for Physics II, ($N=7$).

The engineering tutorial feedback surveys provided qualitative information about student reception of the treatment tutorials. The student responses were graphed for Physics I and sorted by aspect focus ($N=7$). The statements that received the most *agree* and *strongly agree* ratings were two statements, numbers 14 and 15, concerning the application and construction of physics concepts and their use physical components. The next most highly rated statements, numbers 12 and 13, concerned the students understanding of variable interplay in the equations and the advantage or disadvantages of certain solutions. Additionally, one Physics I student commented on the form that, “When I plug in numbers right away, I usually get the answer wrong. When I complete the problem with the letters, and then substitute numbers, I’ll get the right answer.” (Figure 7).

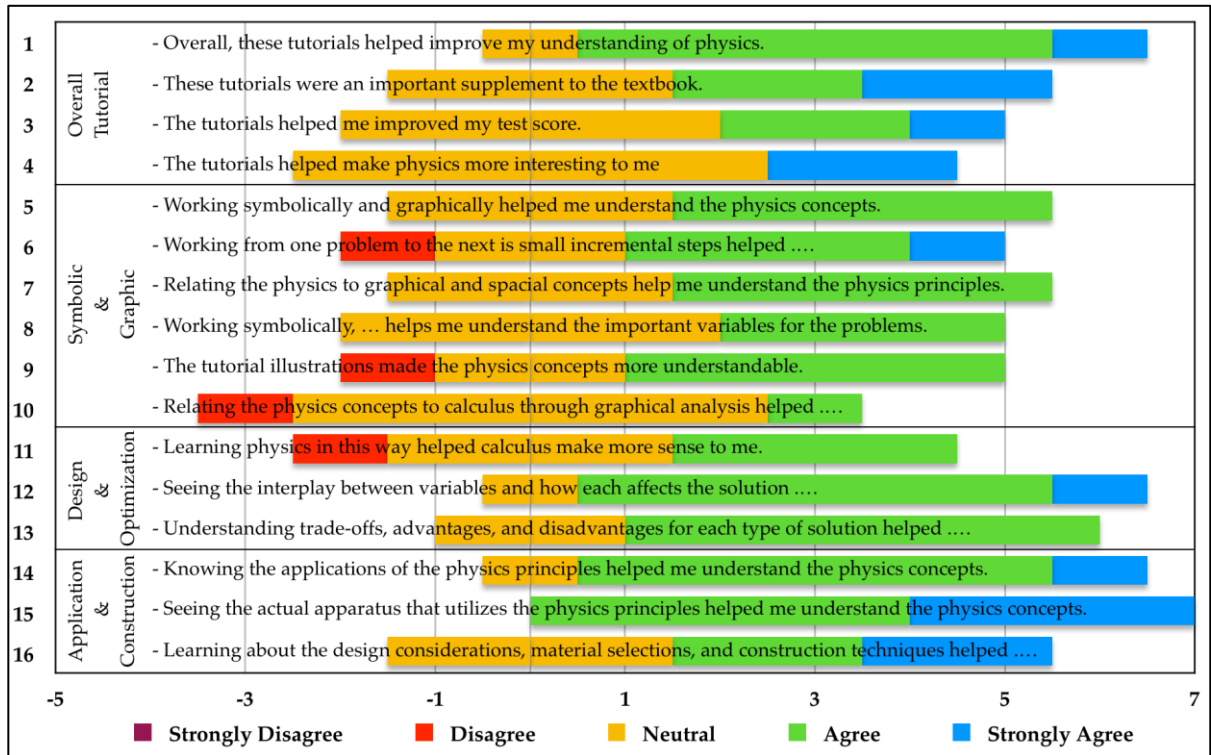


Figure 7. Physics I engineering tutorial feedback survey results, ($N=7$).

The student responses were graphed for Physics II and sorted by aspect focus ($N=7$). The statements that received the most *agree* and *strongly agree* ratings were two statements, numbers 6 and 9, that were about helpfulness of the problem progression and illustrations in the tutorials. The next most highly rated statements, numbers 12 and 13, concerned the students understanding of variable interplay in the equations and the advantage or disadvantages of certain solutions (Figure 8).

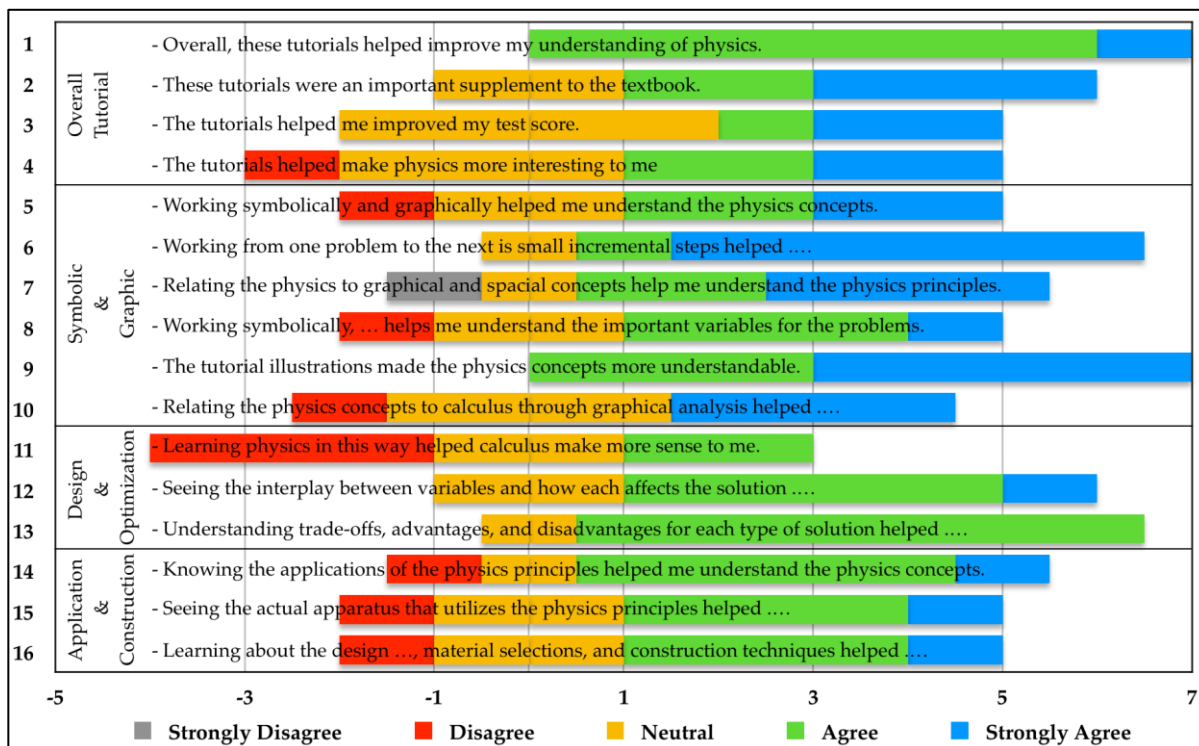


Figure 8. Physics II engineering tutorial feedback survey results, ($N=7$).

Both Physics I and Physics II classes rated the overall tutorial effectiveness highly. The least agreed with statement for both Physics I and Physics II was a statement which related to whether the tutorials had improved the student's understanding of calculus and its relationship to optimization.

College evaluations for the Physics I class averaged 2.90 overall ($N=7$). The Physics II class overall average was 3.55 ($N=7$). One student said, "We went over lots of class questions and went into detail to help understanding." Another stated, the instructor would "explain politely everything we asked, good labs, and relaxed class."

INTERPRETATION AND CONCLUSION

The FCI results for the Physics I course demonstrated that a high level of improvement of conceptual physics knowledge had been achieved during the treatment phase. The total post-treatment normalized gain of 0.38 correlates well to the national average FCI gain of 0.39 for interactive engagement courses. Since the FCI test was administered three times throughout the course, this battery of test administrations allowed for isolation of the gain score due solely to the treatment period. The main course gain before the treatment phase of 0.20 was close to the average gain of 0.22 for traditional courses nationwide. The engineering tutorial treatment imparted an additional gain that matched the traditional course gain, making the total course gain comparable to national interactive engagement courses.

However, the BEMA results demonstrated a low level of improvement from the treatment. The pre-treatment test given just before the final review achieved results more comparable to pre-test scores of students who had not yet taken a Physics II course. The post-treatment conceptual test results did not show a level of understanding as high as either traditional or interactive engagement courses nationwide, and the gain scores did not show a high level of improvement during the treatment phase. While there was an overall improvement, the overall class-wide effect of the engineering tutorial was not strong.

To reveal more insight into the overall results and differences between the classes, the student's individual performance was analyzed. For Physics I, each student's

treatment gain was compared with their pre-treatment gain, total gain, highest concept test score, their engineering tutorial positive feedback percentage and overall course grade (Figure 9).

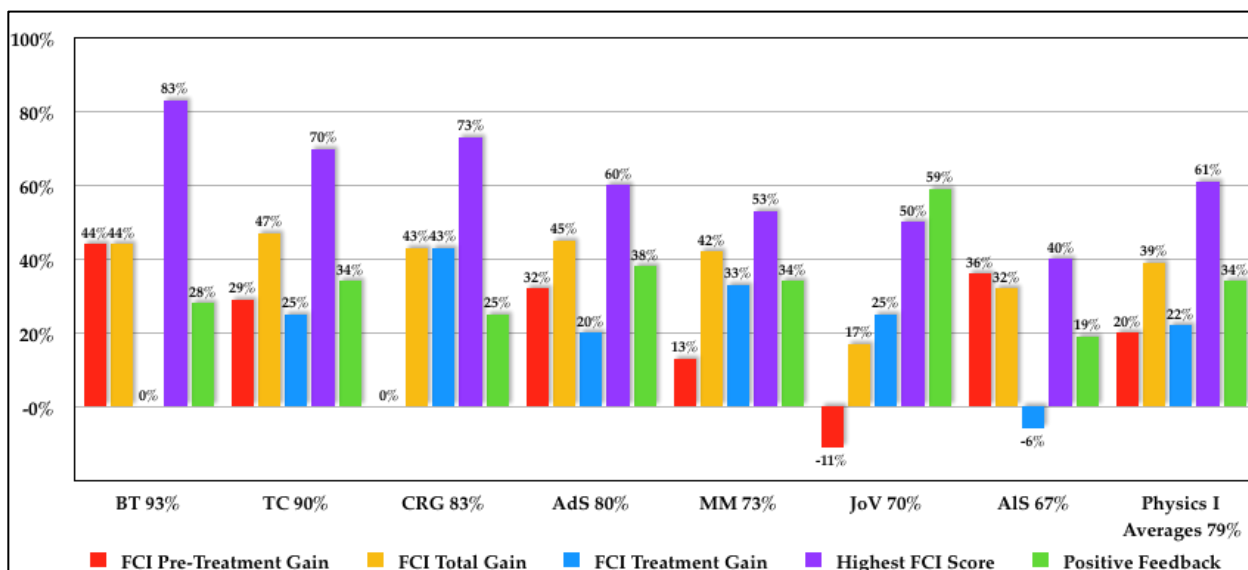


Figure 9. Physics I individual students identified by initials, gains, highest score, feedback, and course grade, ($N=7$).

Looking at individual scores in Physics I, the students with the four highest treatment gain increases, students CRG, MM, JoV, and TC, on the FCI also had three of the four highest engineering tutorial feedback ratings. The students who gave the most positive ratings for the tutorials, students JoV, AdS, MM, and TC, had an average treatment gain of 0.26. It is also notable that this was the middle-to-lower portion of student in the class. While these students did not have the highest total FCI scores, their improvement was remarkable.

The Physics II data is also more informative when analyzed for individual students. Each student's treatment gain was compared with their pre-treatment score,

post-treatment score, engineering tutorial positive feedback percentage and their overall course grade (Figure 10).

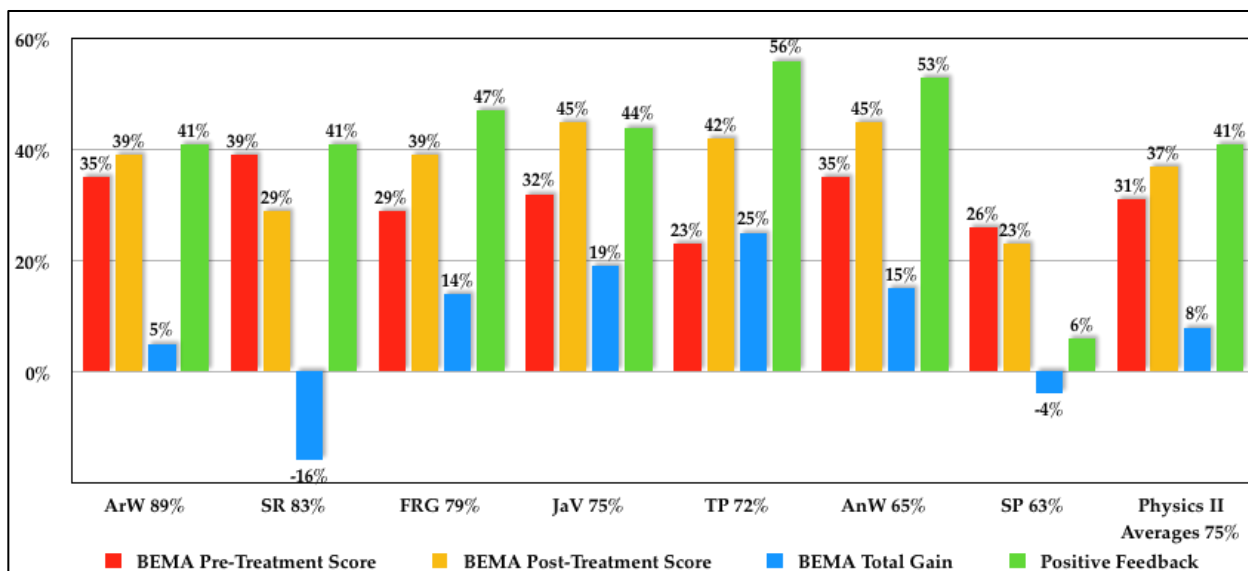


Figure 10. Physics I individual students identified by initials, gains, feedback, and course grade, ($N=7$).

The four students with the highest tutorial feedback ratings, students TP, AnW, FRG, and JaV, also had the highest post-treatment scores and treatment gains, with an average score of 43% and average normalized gain of 18%. This gain is still not commensurate with other interactive-engagement classes as represented by the national data, however, it is a great improvement for a one-week review using the engineering tutorials. Also of importance is that these high scores and gains were in the middle-to-lower portion of students, just as seen in the Physics I group and cited as a benefit of using engineering in physics instruction by Oliver and Kane (2011).

To assess the engineering tutorials' capacity for improving problem solving ability, the results from traditional tests and exams were compared. The students'

performance on their final exam showed improvement after the engineering-tutorial-as-final-review. In the Physics I class, a clear pattern of performance on the conceptual test and final exam grades was apparent, where the highest scores on the final matched FCI performance. The Physics II data is not quite as clear, where the highest BEMA scores were aligned with students who improved their performance on the final exam as compared with previous tests. However, these same students did not score the highest absolute scores on the final exam. As demonstrated in previous studies that correlated conceptual understanding to problem solving ability (Knight, 2002), those students who scored higher on the conceptual tests performed best on the traditional problem-solving-based final exam, particularly for Physics I with the FCI, with performance more mixed with Physics II and the BEMA.

The engineering tutorial's effect on the enjoyment of learning physics is shown best by the engineering tutorial feedback. The highest rated engineering tutorial feedback statements were commensurate with intended results of the treatment. Particularly notable were student responses when asked about the deliberate problem progression of the engineering tutorials (statement 6). Students reported favorable reception to the incremental approach that helps make the principles easier to understand and organize in their minds. Students also highly rated the question concerning symbolic reasoning and its relation to the interplay of variables. This aspect of the tutorials is fundamental to using physics as a tool for an intended outcome. Finally, a great response from a Physics I student on the free response comment was, "When I plug in numbers right away, I

usually get the answer wrong. When I complete the problem with the letters, and then substitute numbers, I'll get the right answer.” This demonstrates that the symbolic approach to teaching also helps minimize arithmetic errors that can arise when numbers are used in the problems prematurely.

VALUE

This action research-based classroom project has been instrumental in my development as a teacher. The crash course through the history of physics education research has been helpful in learning the lessons gained by other physics instructors in effective instruction techniques already tried and proven. Also, being able to model physics instruction around my engineering insight into physics and demonstrate that the engineering approach to physics instruction can be effective has given me confidence as a teacher to blend my experience into the classroom.

Summarizing the students' reception of the engineering tutorials, the students were attentive and very interactive during the final review. Class interaction was strong when asked to predict the performance of a physics system based on manipulation of variables, particularly when students were evenly divided in predictions, and students were asked to defend their position to each other. Additionally, students were curious about the actual construction of devices employing the physics phenomena, as well as the applications of the principles, particularly with Physics II material where the application of electricity, circuits, and magnetics is not as easily comprehended.

The Physics I data was the most compelling, in that the pre-treatment phase of the coursework is in-line with the national averages for lecture-based courses. The increase in normalized gain on the FCI to achieve the average interactive engagement gains after only one week of review work is impressive and shows that the engineering approach to teaching physics is at least as effective as interactive engagement. Looking at the gain from a different perspective, the engineering tutorials doubled the gain-score of the class in only one week of class time. The treatment gain could have been even higher, considering that the top student in the course had already achieved an FCI score much higher than the national average for raw scores, and little improvement from the treatment phase was possible. Perhaps with a more thorough tutorial in the future, improvements at higher levels will also be attainable.

The Physics II data was more mixed. However, the more detailed look at the individual scores showed a correlation in that the students who rated the engineering tutorials highest also had the higher gain-scores for the BEMA. This is true for the four highest rated engineering tutorial feedback scores in Physics II. Also, each of these students were low-performing in the course, and the fact that they had the highest concept assessment gains indicates that the engineering approach may be of the most value in reaching lower-achieving students.

As related to my original intentions for the project, I am still convinced that the approach is sound and has a strong philosophical footing. The perspective of a physics-only approach to understanding a physical phenomenon is different from an engineering

approach which must not only understand a phenomenon, but also engage with it to design a n intended outcome and benefit. This interaction with physics is at a much deeper level, but also more accessible to a student who is just beginning to understand the nature of physics. I compare this perspective with teaching someone to drive a car. I can instruct them on the technical aspects of driving a car, such as how the controls work, traffic rules, and safety guidelines. But until the student tries to use the car to get where they want to go, they don't know how to drive. Similarly, until students try to use physics as a tool to accomplish something, they won't fully understand it.

As I develop the engineering approach to teaching physics, I will attempt to integrate the approach more seamlessly into the primary material of the class. I would like to incorporate project-based learning, such as a rocketry project or circuit design, into the course, as well as smaller problem sets built off of engineering principles. Additionally, other tools, such as inquiry, classroom assessment techniques, and peer-instruction could be included in the course. Overall, this was a rewarding experience and a fulfilling challenge.

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APPENDICES

APPENDIX A

INSTITUTIONAL REVIEW BOARD EXEMPTION APPROVAL



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 0000165

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Administrator:
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MEMORANDUM

TO: Christopher Shaw and John Graves
FROM: Mark Quinn, Chair *Mark Quinn CJ*
DATE: December 10, 2015
RE: "Advanced Engineering Tutorials in College Physics" [CS121015-EX]

The above research, described in your submission of December 10, 2015, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.

APPENDIX B

PHYSICS I TUTORIAL EXAMPLE

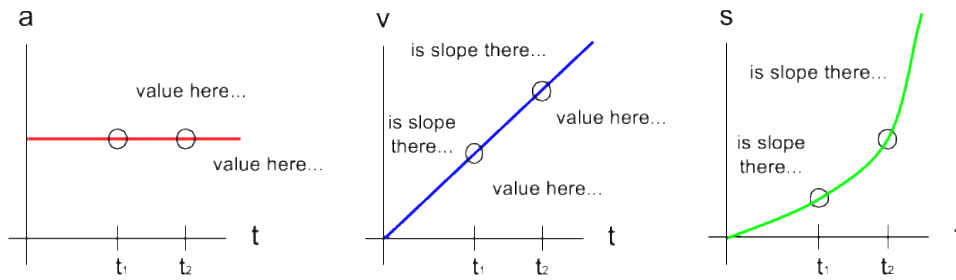
Kinematics:

acceleration (a) = rate of change (time derivative) of **velocity (v)**

$$a = \frac{dv}{dt}$$

velocity (v) = rate of change (time derivative) of **position (s)**

$$v = \frac{ds}{dt}$$

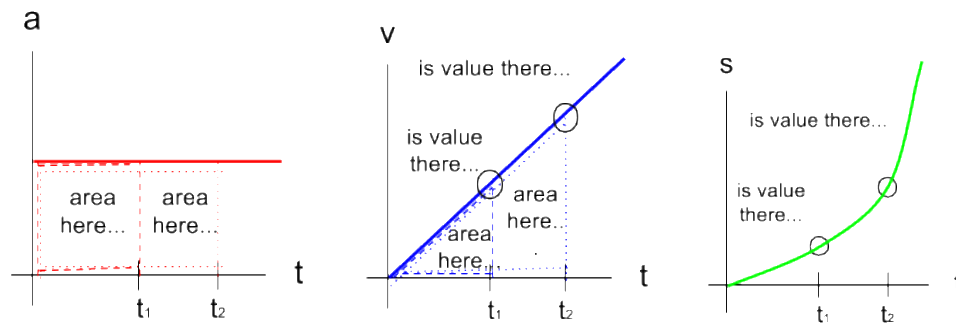


distance (s) = cumulative sum (time integral) of **velocity (v)**

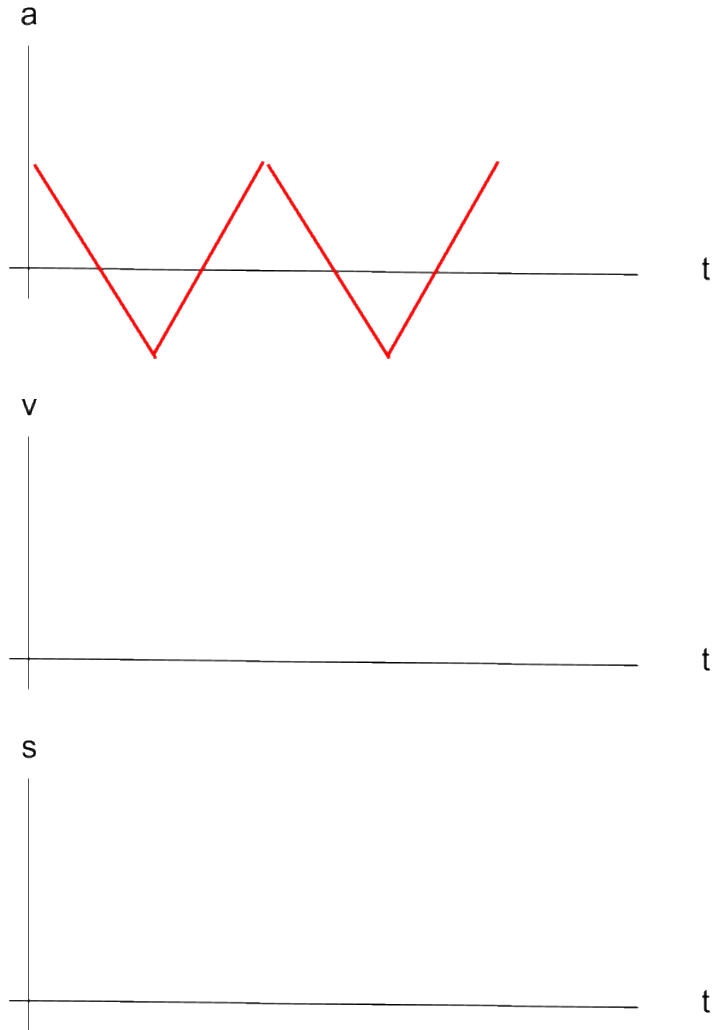
$$s = \int v dt$$

velocity (v) = cumulative sum (time integral) of **acceleration (a)**

$$v = \int a dt$$

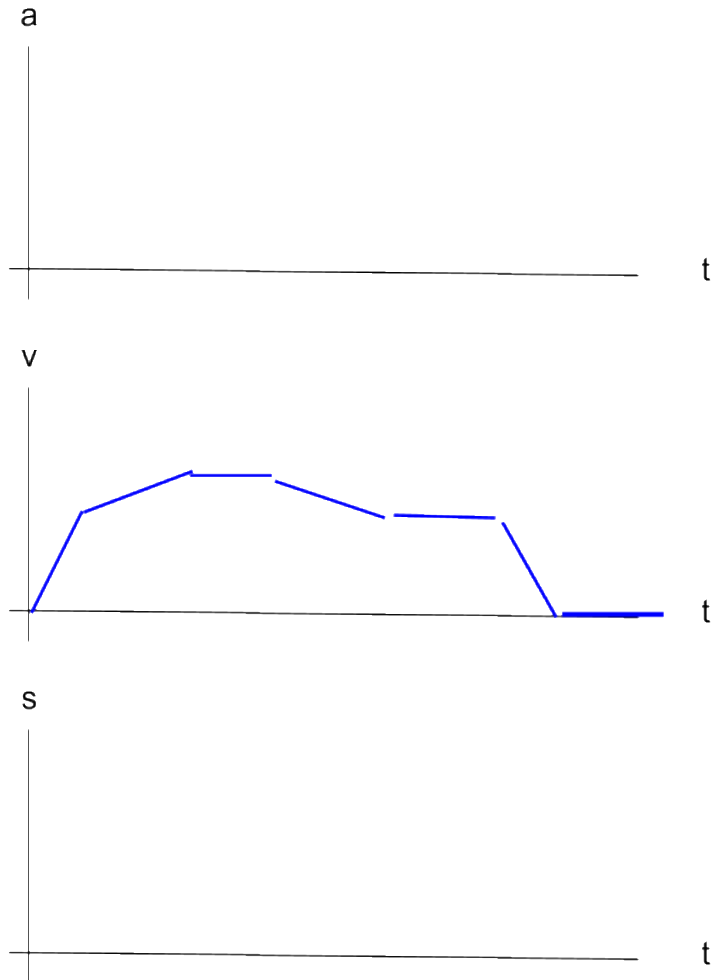


Build velocity and position graphs from the shown acceleration:

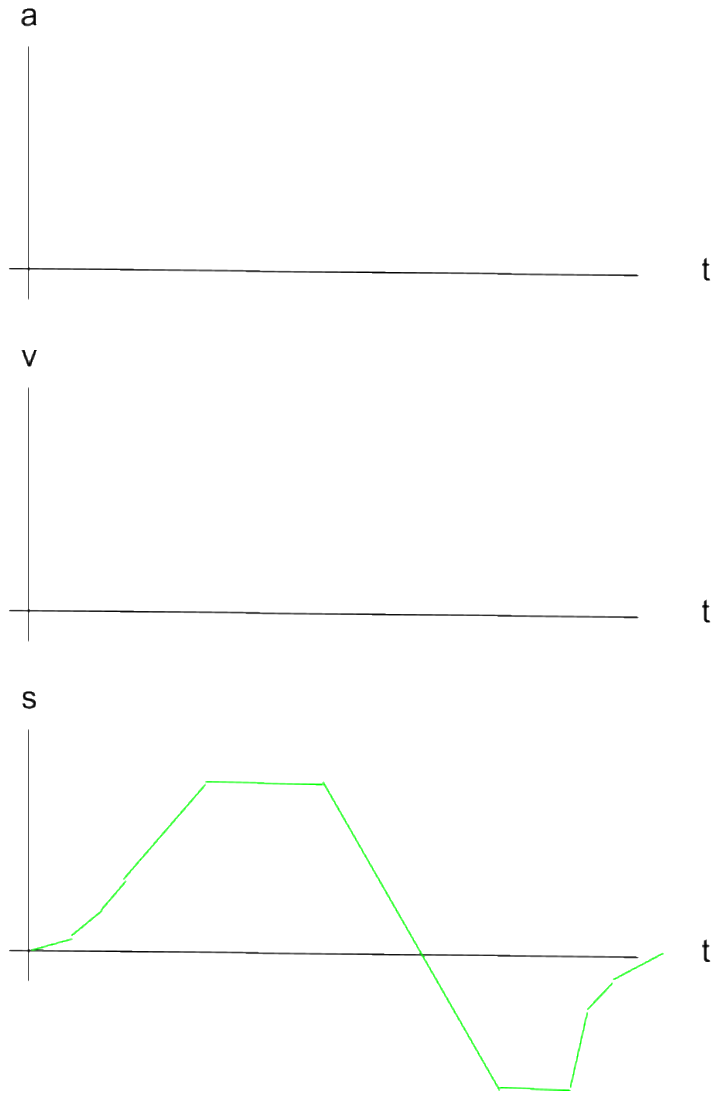


Bonus points: Describe a possible system that this acceleration profile approximates:

Build acceleration and position graphs from the shown velocity:



Build acceleration and velocity graphs from the shown position:



Projectile Motion:

Objects in a uniform gravity field all fall with a constant speed when not subject to outside forces. Motion in each spatial dimension is independent of the motion in other spacial dimensions.

Vertical equations of motion for constant acceleration:

$$a = -g \qquad v = \int a \, dt = at + v_0 \qquad s = \int v \, dt = \int at + v_0 \, dt = \frac{1}{2}at^2 + v_0t + s_0$$

Horizontal equations of motion for constant velocity:

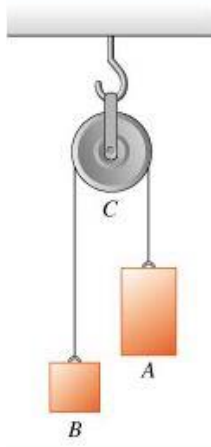
$$v = v_0 \qquad s = \int v \, dt = \int v_0 \, dt = v_0t + s_0$$

Important trigonometric identities:

$\theta =$	0	30	37	45	53	60	90
$\sin \theta =$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos \theta =$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan \theta =$	0						

Kinetics Tutorial

Answer the following questions about each system:

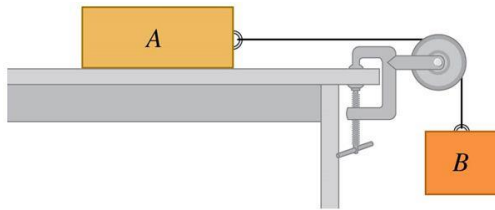


Write the equation of motion ($a=F/m$) for the system:

Explain the terms that make up the driving force (F) part of the equation:

Explain the terms that make up the inertial resistance (m) part of the equation:

If we included the mass of the pulley, where in the equation would the term be located?



Write the equation of motion ($a=F/m$) for the system:

Explain the terms that make up the driving force (F) part of the equation:

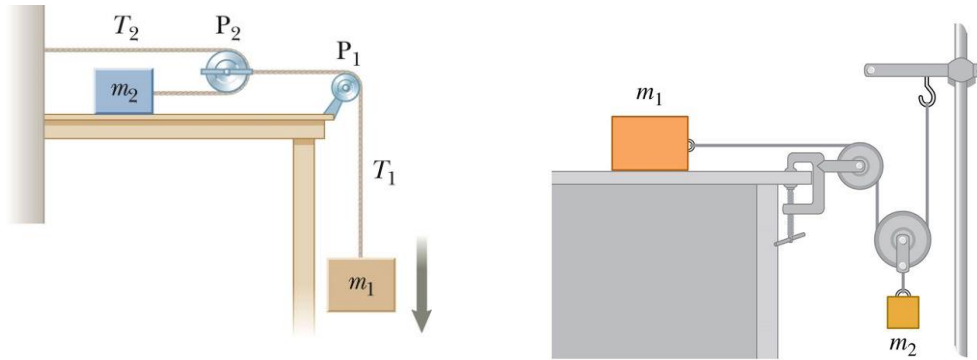
Explain the terms that make up the inertial resistance (m) part of the equation:

If we included the friction from block A and the table or the friction in the pulley, where in the equation would the term be located?

If we included the mass of the pulley, where in the equation would the term be located?

As the mass of block A approaches 0, what value does the acceleration of the system approach?

As the mass of block B approaches infinity, what value does the acceleration of the system approach?



Write the equation of motion ($a=F/m$) for each system and compare the two:

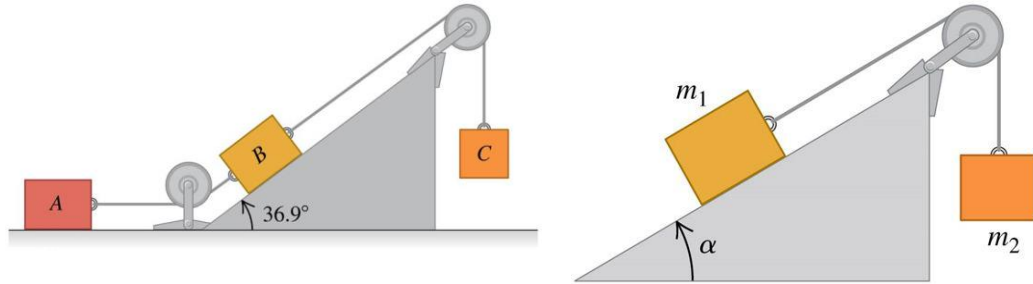
$$a_1 = m_1 g /$$

Explain the terms that make up the driving force (F) part of the equations and compare the two:

Explain the terms that make up the inertial resistance (m) part of the equations and compare the two:

As the mass of the block on the table approaches 0, what value does the acceleration of the each system approach?

As the mass of the hanging block approaches infinity, what value does the acceleration of the each system approach?



Write the equation of motion ($a=F/m$) for each system including friction and simple disc pulley inertia and compare the two:

Explain the terms that make up the driving force (F) part of the equations and compare the two:

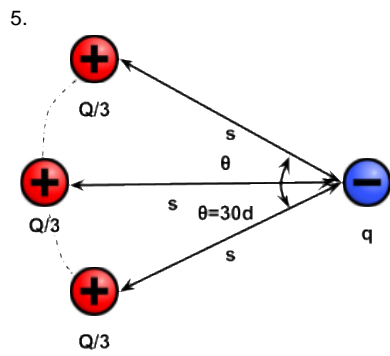
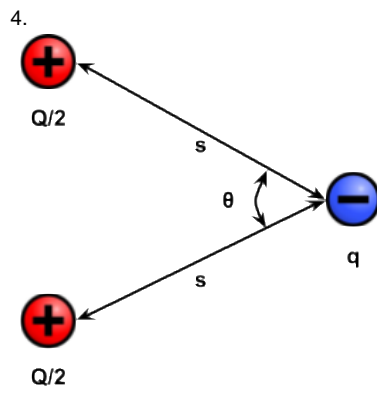
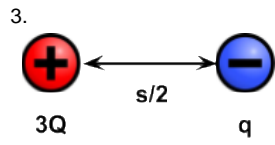
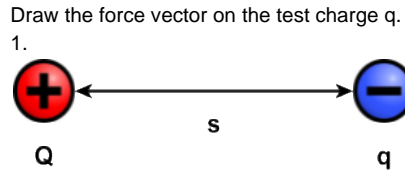
Explain the terms that make up the inertial resistance (m) part of the equations and compare the two:

APPENDIX C

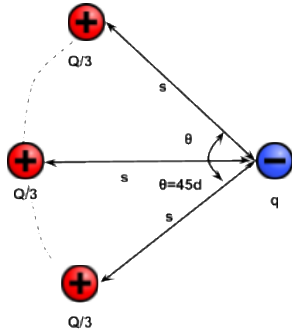
PHYSICS II TUTORIAL EXAMPLE

Electrostatics Tutorial Part A: Force

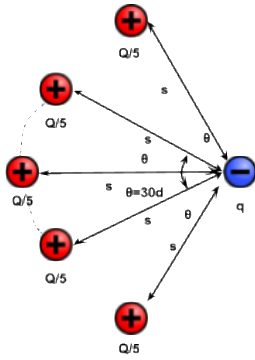
Determine the symbolic expression for the electrical force on the test charge q .



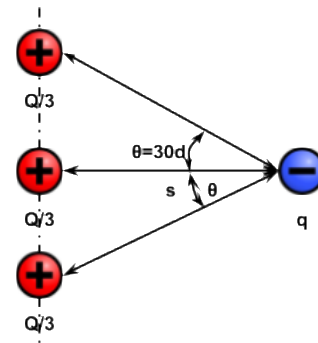
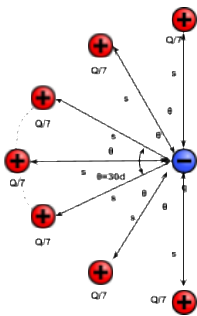
6.



7.



8.



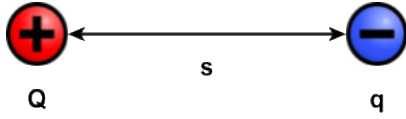
9. Since off-axis charges don't add as much force, what engineering purpose would there be to using curved conductors.

10. What happens if you continue to add more partial charges eventually completing the circle? What engineering component using this property?

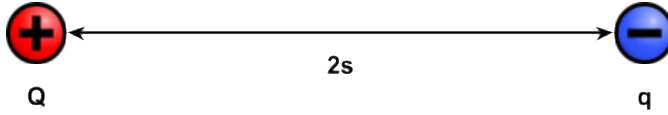
Electrostatics Tutorial Part B: Field

Determine the symbolic expression for the electrical field at the test charge q .
Draw the field vector on the test charge q .

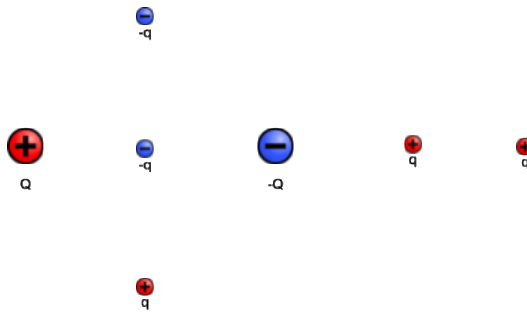
1.



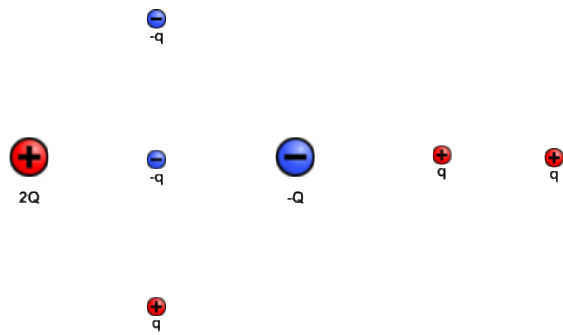
2.



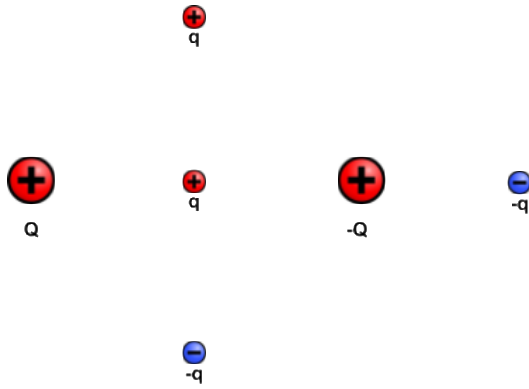
3. Draw the electric field lines for the charges shown. Draw the force vectors for the test charges shown. Rank the electric field from highest to lowest at the test charge locations shown.



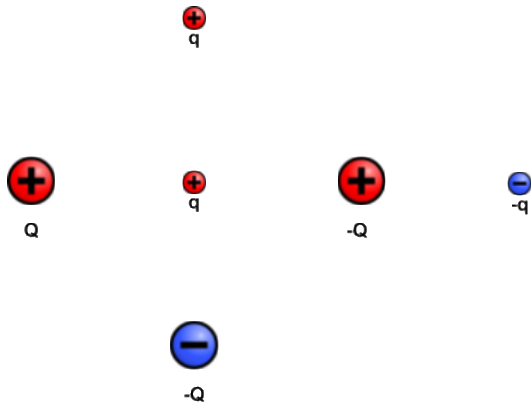
4.



5.



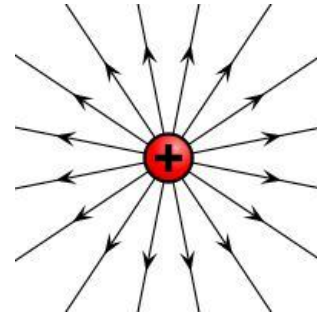
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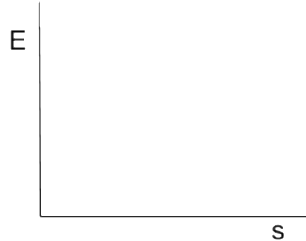
7. What geometric shape is created by expanding a Gaussian surface symmetrically from a point charge?

What is the equation of the area of this surface?

As the Gaussian surface is expanded, the electric field is distributed evenly throughout the area. What is the proportional relationship between the field strength and the radius of the gaussian surface?



Graph the electric field intensity vs distance from the charge s :

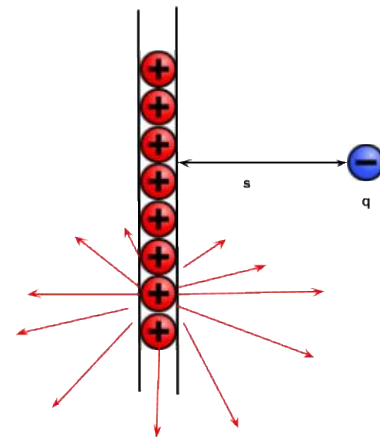


8. What geometric shape is created by expanding a Gaussian surface symmetrically from a line charge?

What is the equation of the area of this surface?

As the Gaussian surface is expanded, the electric field is distributed evenly throughout the area. What is the proportional relationship between the field strength and the radius of the gaussian surface?

Graph the electric field intensity vs distance from the charge s :

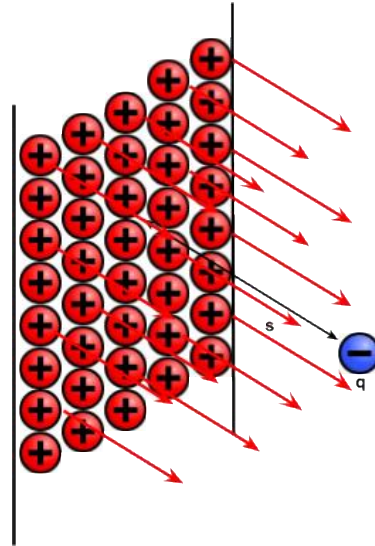
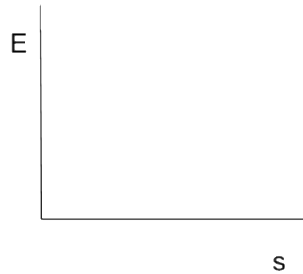


9. What geometric shape is created by expanding a Gaussian surface symmetrically from a line charge?

What is the equation of the area of this surface in terms of distance?

As the Gaussian surface is expanded, the electric field is distributed evenly throughout the area. What is the proportional relationship between the field strength and the radius of the gaussian surface?

Graph the electric field intensity vs distance from the charge s :



10. What can you tell about the orientation of the field lines and the strength of the electric field?

For the point charge, does the force needed to move the test charge decrease, increase, or remain constant as s increases?

For the line, does the force needed to move the test charge decrease, increase, or remain constant as s increases?

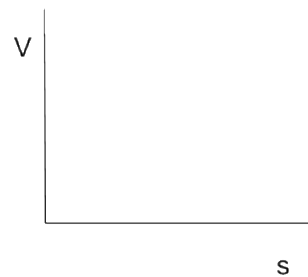
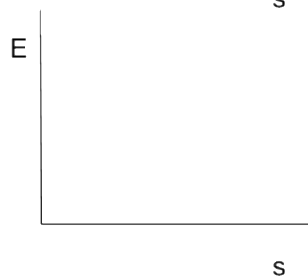
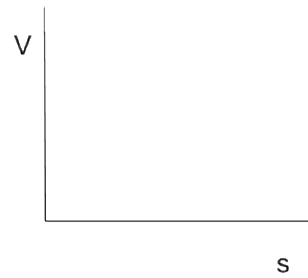
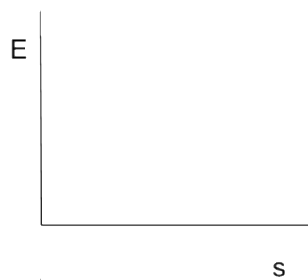
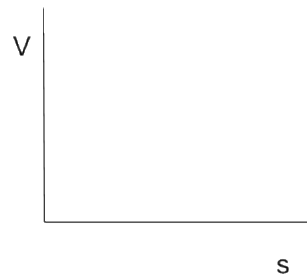
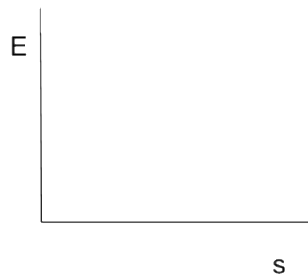
For the plane charge, does the force needed to move the test charge decrease, increase, or remain constant as s increases?

What is the expression for the work required to move the test charge away from the plane charge in terms of E , s , and q ? What about in terms of F and s ?

12. Given that work is a measure of energy, and work done against a field force increases potential energy, we define the term electric potential (V) as the potential energy per unit charge. Derive the equation of dV in terms of E and ds starting from the equation $dW = -Fds$.

Rearrange the above equation to show that the electric field is the ratio of two differential elements:

13. Copy the E s graphs from above, and draw the corresponding V s graph:



14. If we use iso-elevation lines the picture to the right to represent equipotential lines in an electric field, identify the following:

Areas of greatest electrical potential (V).

Areas of least electrical potential (V).

Areas of highest electric field (E).

Areas of lowest electric field (E).

Draw examples of electric field vectors on the map.

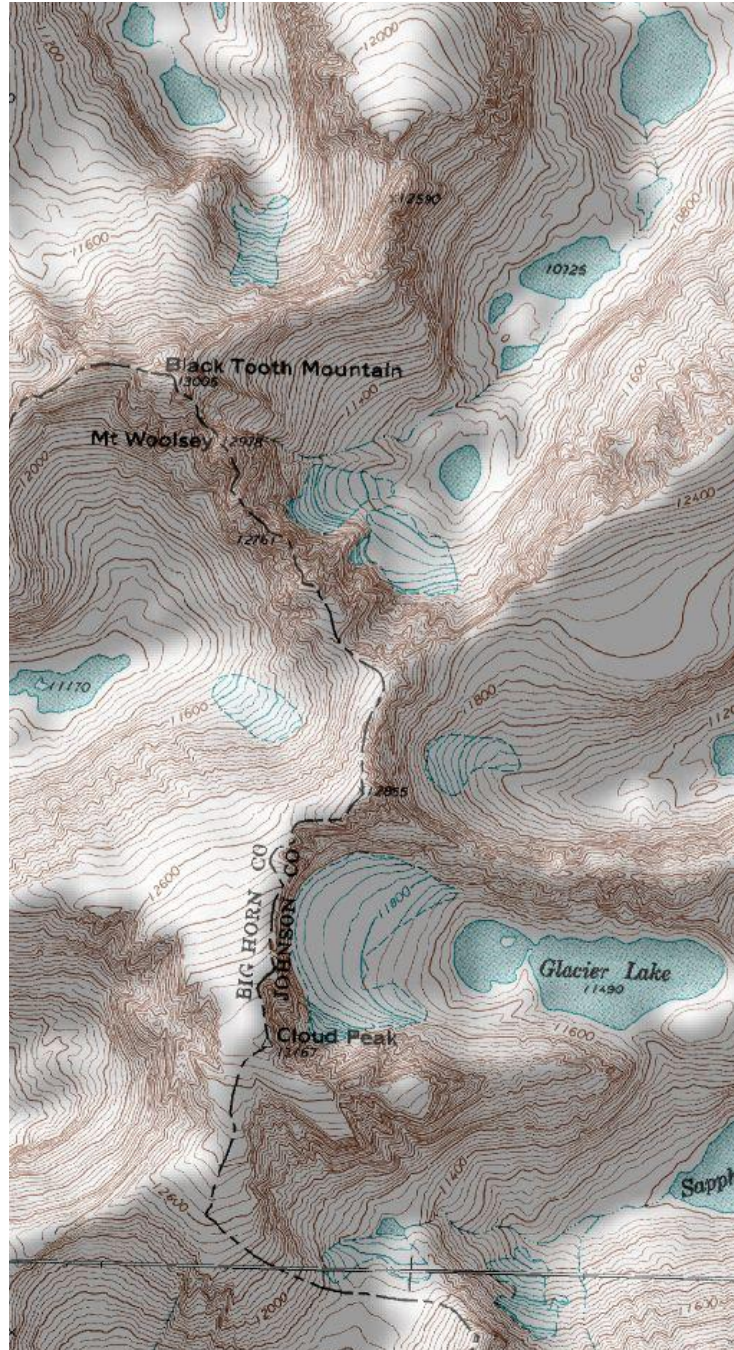
Rank the glaciers from highest to lowest electrical potential.

Which side of Cloud peak has the higher electric field?

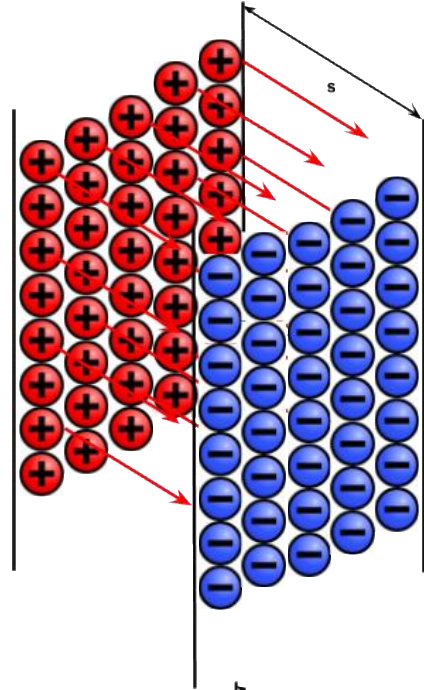
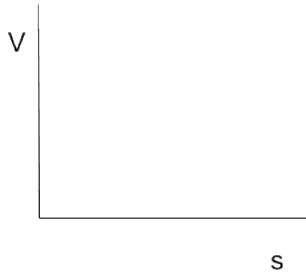
Which side of Black Tooth has the higher electric field?

Is the electric field at the top of Cloud Peak high, low, zero, or undetermined?

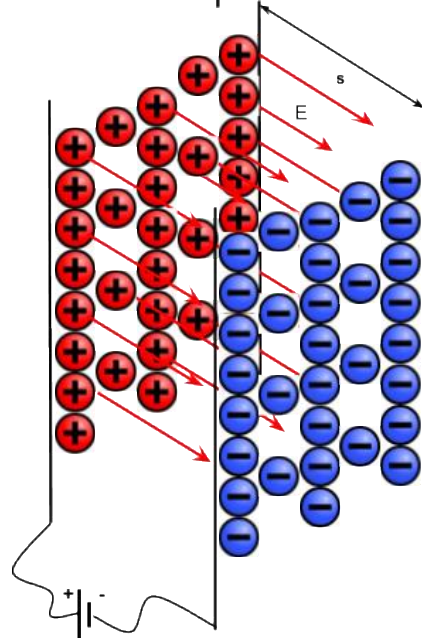
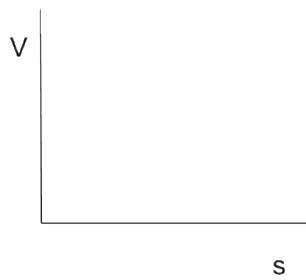
Is the electric field of Glacier Lake high, low, zero, or undetermined?



15. Show how the Vs graph for charged parallel plates varies with increasing distance.



16. Show how the Vs graph for energized capacitor varies with increasing distance.



APPENDIX D

ENGINEERING TUTORIAL FEEDBACK SURVEY

Participation in this research is voluntary and participation or non-participation will not affect a student's grade or class standing in any way.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1 - Overall, these tutorials helped improve my understanding of physics.	5	4	3	2	1
2 - These tutorials were an important supplement to the textbook.	5	4	3	2	1
3 - The tutorials helped me improved my test score	5	4	3	2	1
4 - The tutorials helped make physics more interesting to me	5	4	3	2	1
Symbolic, graphical, spatial analysis:					
5 - Working symbolically and graphically helped my understand the physics concepts.	5	4	3	2	1
6 - Working from one problem to the next is small incremental steps helped me understand the physics concepts behind the formulas.	5	4	3	2	1
7 - Relating the physics to graphical and spatial concepts help me understand the physics principles.	5	4	3	2	1
8 - Working symbolically, even though it yield equations that only apply to very specific systems, helps me understand the important variables for the problems.	5	4	3	2	1
9 - The tutorial illustrations made the physics concepts more understandable.	5	4	3	2	1
10 - Relating the physics concepts to calculus through graphical analysis helped me understand the physics principles	5	4	3	2	1
11 - Learning physics in this way helped calculus make more sense to me.	5	4	3	2	1
12 - I'm really not reading this survey, and am just checking random boxes. Please mark Strongly Disagree if you are actually reading the statements. Otherwise your survey will not be counted.	5	4	3	2	1
13 - Seeing the interplay between variables and how each affects the solution helped me understand the physics concepts.	5	4	3	2	1
14 - Understanding trade-offs, advantages, and disadvantages for each type of solution helped me understand the physics principles.	5	4	3	2	1
Real-world construction:					
15 - Knowing the applications of the physics principles helped my understand the physics concepts.	5	4	3	2	1
16 - Seeing the actual apparatus that utilize the physics principles helped my understand the physics concepts.	5	4	3	2	1
17 - Learning about the design considerations, material selections, and construction techniques helped my understand the physics principles.	5	4	3	2	1
18 Any feedback as to how to make the coursework more understandable:	_____				

Note: Question 12 is an attention check question, so questions 13-17 are referred to by question numbers 12-16 in the text.

APPENDIX E
COLLEGE COURSE EVALUATION FORM

Student Evaluation of Faculty Performance

Please enter the course ID for the class being evaluated. Write the numbers in the boxes and color the ovals corresponding to your entry, making sure to darken the ovals completely. Please complete both sides of this evaluation.

Course ID

0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9
0	1	2	3	4
5	6	7	8	9

PLEASE USE NO. 2 PENCIL

RIGHT	WRONG
● ● ●	✓ ● ✕ ●

I am a Freshman
 Sophomore
 Other

This course is a requirement
of my academic program. Yes
 No
 Unsure

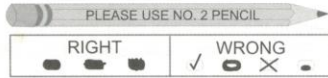
Your comments are very important to us. Please take a few minutes to respond to the following questions.

1. What specific things did this instructor do that helped you learn the material in this course? Your comments could consider things such as classroom activities, group work, assignments, lecture techniques, assessment techniques, course resources, or classroom attitude.

2. Are there specific things that this instructor might have done that would have helped your learning? If so, please list them.

3. Describe at least one specific thing you, as a student, could have done to improve your learning in this course.

OVER PLEASE →



Using a No. 2 pencil, please respond to the following questions by coloring the bubble below the answer that best fits your response. If you change your mind, carefully erase your mark and make another choice.

Please use the following scale to rate your instructor on the items below.

	Strongly Agree	Agree	Disagree	Strongly Disagree	
1. The assignments I was expected to complete helped me in understanding course material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
2. My instructor gave tests, projects, etc. that addressed course objectives.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
3. My instructor was enthusiastic about the course material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
4. My instructor was willing to listen to student questions and opinions.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
5. My instructor explained how course requirements would be used in determining my grade.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
6. My instructor helped me to apply course material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
7. My instructor explained course material clearly and concisely.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
8. I felt the quality of instruction in this course contributed to my learning, despite how I might feel about the content itself.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
9. My instructor used appropriate techniques (examples, demonstrations, activities, etc.) to clarify course material.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■

Your instructor may ask for your response to several course-specific questions. Please respond to those questions below.

10. Optional question #1	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
11. Optional question #2	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
12. Optional question #3	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
13. Optional question #4	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
14. Optional question #5	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■
15. Optional question #6	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	■