Hands-On Teaching of Engineering Fundamentals

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Abstract

Driven by ABET2000 requirements, input from an industry-based Board of Advisors, and feedback from students and alumni, The University of Tennessee College of Engineering is well underway in a major renovation / reconstruction of its Freshman Engineering program. This effort is an integrated approach to the Freshman curriculum, with a 6-semester hour first-semester course emphasizing problem-solving, teamwork, design concepts, and computer tools (engineering graphics and computer programming), all based around the study of low-level introductory physics material. The second thrust is a second-semester 6-hour course integrating statics and dynamics, while assuming and using mastery of the material from the first semester.

Following the lead of educational theorists, the effort is trying to include as many different forms of learning opportunities as possible. The learning cycle begins with a classroom lecture to introduce the concept, a hands-on laboratory "physical homework" experience to encourage student ownership of the concept, a recitation-style working session to provide practice with the tools available in using the concept, homework assignments to provide practice, and a team design project requiring mastery and application of several of the concepts. This report concentrates on the importance of and techniques used in the hands-on laboratory setting.

The hands-on laboratory physical homework is designed to help students personalize and "feel" the concept. To this end, it uses very simple experiments and includes analyses of experimental results. These experiments are devised using the following general guidelines:
1) the scale of the experiment should be within the normal range of the student's experience;
2) students should (literally) feel the physical process they are trying to measure;
3) differences between situations should be very noticeable and easily measured;
4) data collection tools should be crude and easy to use;
5) data uncertainty and its implications are emphasized throughout.

This report describes the reasoning behind and structure of the lab experiences, and provides examples of specific experiments based on these principles.

Introduction

The University of Tennessee College of Engineering began some years ago to examine its Freshman Engineering program. Advice on the current state of the program and on what should be changed was sought from current students, alumni, College faculty, and an industry-based Board of Advisors. The messages that came back were loud and clear, and were very much in keeping with the goals of ABET2000[1]. According to those polled, the Freshman Program must do the following: 1) integrate the course material to enhance learning; 2) require more teamwork and design projects; 3) teach better communications skills; and 4) emphasize problem-solving skills, including an engineering approach to problems, easy familiarity with unit conversions, and a basic sense of "reasonableness." Above all, the feedback demanded that the Freshman Program be seen as the most important part of the curriculum, in that it prepares the students for all other coursework. These goals are consistent with those of other engineering educators[2], and with the current view of the needs of industry[3].

The major renovation resulting from this work is now well underway, having completed the first semester of instruction with a pilot group of 60 students (out of the 450-500 freshmen). The program is an integrated approach to the freshman curriculum, starting with a six-hour first-semester course emphasizing problem-solving, teamwork, design, and computer tools (engineering graphics and computer programming), all based on the study and use of low-level introductory physics. In the second semester students will take another six-hour course of integrated statics and dynamics. This course will assume mastery of the techniques and tools from the first semester, and will force students to make extensive use of those tools.

Based on experiences in previous courses and following the lead of such educational theorists as David Kolb[4] and his proponents[5], the renovation effort tries to include as many different forms of learning as possible. These are organized into a learning cycle, and there are generally two such cycles per week. Each cycle contains a standard classroom lecture to introduce the concept, a hands-on laboratory "physical homework" experience to encourage student ownership of the concept, an Analysis and Skills recitation-style working session to provide practice with the tools available in applying the concept, a traditional homework set designed to force repeated use of the concept, and a team design project requiring mastery and application of several of these concepts.

The hands-on laboratory uses very simple demonstrations, experiments, and analyses of the experimental results to help students truly appropriate and "feel" the concept. These have proven to be a very important part of the overall effort, and have been cited by both students and involved faculty as being crucial to the improved understanding of the material. This is very much in keeping with the experiences of other educators using hands-on learning methods[6].

The remainder of this report describes in general terms the approach to the hands-on lab, defines the guidelines used in developing the specific experiences, describes how these are structured through the first semester of the new coursework, and provides examples of specific experiments. Finally, the report includes a look back at lessons learned from the first semester's effort.

Approach

The purpose of each experience is to help students develop a physical "feeling" for the concept most recently presented in the classroom lecture. To accomplish this, the experience must do three things: 1) briefly restate and reinforce the background and the concept; 2) give students a physical experience with the concept; and 3) require students to analyze the physical results in light of the concept. The goal is to force the student to use the concept to figure out how to approach the physical example, and then to apply the physical example to describe the concept.

The hands-on learning experience is sold to the student as a "physical homework" assignment to emphasize that this is something the student must do, and not simply a demonstration that the professor thinks is "cool." Students work in pairs (to encourage peer teaching), and their work is judged by the faculty member or graduate assistant staffing the lab. This judgement is on a proficiency basis, which means that both students in the pair must demonstrate a grasp of the concept and an ability to use it. If either student fails to show proficiency the pair is sent back for more experimentation and review until they can prove proficiency. Once they have done so, they receive full credit for the assignment.

For each experience students are provided with a two-page worksheet. This begins with a half-page summary of the material presented in lecture, refreshing the development of the concept and serving as additional study notes. In addition, this background material develops any equations necessary for the assignment. The worksheet continues with a step-by-step guide to the experiment itself, describing what needs to be done and what data should be collected. This is followed by an Analysis section, which asks general questions about the behavior of the experiment and the results. These questions often require substantial thought, and their object is to force students to approach the concept from as many different angles as possible.

Where possible, each experience tries to reuse and further develop concepts covered in previous sessions. For example, the experiment on moments amplifies and builds on treating forces as vectors, referring back to an earlier lab. The best examples of this occur when a specific lab set-up can be used for more than one experiment.

Each lab experience is expected to take one hour of the student's time. Because it is seen as a homework assignment and not a formal laboratory session, students schedule their own time in the lab, which is open from after the lecture session until late in the evening, and then through the following morning and up until the cycle's Analysis and Skills session. In its current form this gives the student an eight-hour block in which they can freely schedule one hour.

Specific Guidelines for the Hands-On Experiences

The hands-on experiences usually consist of some very simple experiment, data collection, and data analysis. Based on this semester and five years of experience with a smaller similar effort, the experiments themselves are devised following some specific guidelines, which are:

1) the scale of the experiment should be within the normal range of the students' everyday experience. For example, if they are measuring distances, we ask them to deal with distances they might normally measure, perhaps ranging from several millimeters up to several hundred meters. Asking them to deal with minute or extremely large distances, forces, times, or other parameters will do little to enhance their understanding of the concept;

2) students should feel (literally) the physical process they are trying to measure. For example, in measuring moments they should have to actually hold the torque wrench or push on the lever;

3) following from points one and two above, if the concept is used to show differences, the differences should be easily noticeable. For example, we ask students to lift a 10-kg mass directly and then through a moving pulley. They can easily feel the difference between the required forces. Though the concept is just as valid if using a 100-g mass, it is much harder for the students to feel the difference;

4) data collection devices should be as simple and deliberately crude as possible to keep students from being awed by the data collection system and forgetting the basic concept. Our primary data collection tools consist of yardsticks and 30-foot tape measures (since almost all of our analyses are done in metric units this gives good practice with unit conversions), stopwatches, and spring scales. The students will have many opportunities in later classes to learn about more sophisticated devices and what is possible in data collection, but that is not the point here;

5) data uncertainty and its implications are emphasized throughout. One advantage of the crude data collection techniques is that the students can "feel" (cycling back to point 3 above) how uncertain their results really are, while more sophisticated techniques give the illusion of accuracy. Students are asked repeatedly to discuss how much confidence they have in their results, and how things might be different if their results had more or less accuracy.

These guidelines can be summarized into a single motto: make it simple, crude, and big. This raises concerns for some, because the lab often looks more like something that could be pulled together in your garage than like a state-of-the-art teaching laboratory in a sophisticated major university. With which are the freshmen likely to feel more comfortable and at ease? This may be a substantial shift for engineering educators, who enjoy playing with and showing off the fancy gadgets, but too often students get lost in the gadgetry and don't understand the basic concepts.

Structure of the First-Semester Hands-On Experiences

The material in the new first-semester course begins with very basic physical and mathematical tools, and then moves into general introductory mechanics taught from a physics perspective. It follows closely the material and approach suggested by Arons[7], but emphasizes the use of these tools in engineering problems. Added to this at the end of the semester is a very basic description of the laws of conservation, with material pulled from a variety of sources. The material taught in each lecture and a summary of the corresponding hands-on experience are shown in Table 1.

Examples of Specific Experiments

Attached to the end of this report are four examples chosen from the 17 different worksheets given to the students for working through hands-on experiences in this first semester. These examples represent a session from the introductory material at the beginning of the course (Lab 1.3), a session introducing a basic mechanics concept (Lab 4.3), an experience in the core of the introductory static equilibrium material (Lab 5.2), and the experiment to introduce conservation of energy (Lab 6.1). These examples demonstrate the presentation of the background material, the steps through which the students must go, and the analyses they are expected to perform before the laboratory staff will check them off as proficient.

A Look Back and Forward

Based on the positive feedback from the graduate teaching assistants and the students, the hands-on laboratory experiences have been a valuable part of the learning cycle. The students seem to have a much better grasp of the concept, which makes the paper-and-pencil homework problems be more of a practice session with a comfortable tool rather than a random waving of magic wand equations. Not all students grasp all the concepts, but in comparing performance to traditional approaches we believe that the serious students come away from the learning cycle with a better chance of understanding the basic scientific principles . We are collecting data to support and quantify this belief.

With an improved understanding of the basics, supplemented by a semester's worth of problem-solving and team design exercises, the freshmen should be better equipped to handle the material taught in the statics-dynamics course in the second semester. This should translate into better scores on a final we intend to give in common with the traditional statics and dynamics courses next semester.

The learning cycles and the hands-on lab experiments will be carried into the study of statics and dynamics. Much of the same material covered in the first semester will be revisited, albeit much more thoroughly. Many of the same lab experiments will be re-used, adding layers of complexity to the understanding and raising expectations for student understanding and synthesis.

One realization of the past few years is that freshmen no longer come equipped with a basic intuitive understanding of mechanics from work in the fields, the shop, or the garage. Though our hands-on learning experiences cannot replace the years of doing, they do provide some of the same opportunity to link engineering principles and concepts with something the students can feel. That can only improve students' skills and satisfaction as they face the challenges of the new engineering world.

References

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These four faculty represent the teaching faculty involved in this effort, but the success of the effort is owed to the support of the Deans of The College of Engineering and to the other faculty involved in the project over the past three years.

Table 1. Lecture Material and Associated Learning Experience

Lecture Material	Hands-On Learning Experience
unit conversion and estimation	- estimating lengths, areas, volumes, weights, times - establishing the pace as a measurement unit
significant digits, meanings of ratios	- estimating densities of irregular objects by geometric approximation, volume displacement, and mass displacement
basic trig. identities as ratios	- estimating heights of trees and buildings by sighting (see example 1.3)
position and velocity	- measuring velocities - graphs of position and velocity vs. time
acceleration	- measuring accelerations - graphs of position, velocity, and acceleration - working with data variability
combining position, velocity and acceleration	- graphing position, velocity, and acceleration vs. time for various physical situations (ball bouncing, ball rolling, etc.)
mass and weight	- measuring mass through acceleration - weights on a string
forces and $F = ma$	- acceleration on an air track
forces in relation to acceleration graphs	- friction forces - position, velocity, and acceleration graphs
free-body diagrams	- FBD's for a range of situations
introduction to vectors	- lifting weights with forces at various angles - breaking vectors into components
introduction to moments	- forces on the legs of a free-standing ladder - forces on a ladder leaning against a wall - estimating the center of gravity
static and dynamic equilibria	- explain a platform scale - explain a pulley system
rotational motion	- calculating the moment of inertia
mass & energy conservation	- conservation of energy: in springs, balls and elastic cord
conservation of momentum	- colliding balls

Lab. Worksheet 1.3

Height Estimation

EF101 – Engineering Approach to Physical Phenomena

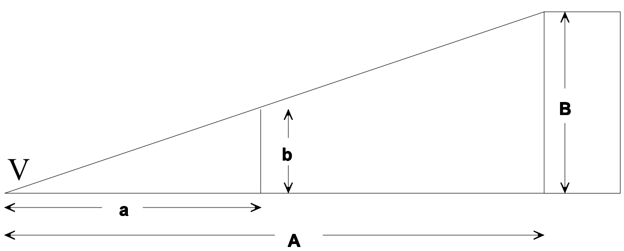
Fall, 1997

Objectives:

- introduce you to a method of estimating height
- extend the concepts of measurement uncertainty looked at in previous labs
- provide practice in the use of basic trigonometric relationships

Background

We talked in class about the use of trigonometric relationships to define the angle between lines. In this lab we will use those basic concepts to develop a tool that will allow you to estimate the heights of large objects. The basic concept is shown in the figure. If we can establish the two lines, then the ratios of the sides will always be same. So, if what we're trying to do is find the height B, if we know the ratio b/a and the length A, then B = A * (b/a). For example, if b is 1/10 a (so b/a = 1/10) and A = 50 ft, then B = 50 ft * (1/10) = 5 ft. This is most easily thought of in terms of ratios, where the ratio b/a means that we have 0.1 units of length of height for every unit length of horizontal distance. Since we have 50 ft of horizontal distance A, for every ft of this we have 0.1 ft of vertical distance B, or B = 50ft horizontal length *(0.1 ft vertical length / ft horizontal length) = 5 ft.



What we'll do for this lab is put our eyeball at the vertex of the triangle (pt V), and use some known lengths a and b to establish the ratio. We then line up the top of the height we're trying to measure with the top of b, and the bottom with the bottom, which ensures that we have a situation as shown above. We will then pace off A to get its length, and calculate B.

Procedure

Task 1. Measuring length b.

Hold your hand in the gaging position (thumb and pinkie both extended about as far as they can go, out at arm's length), and have your partner measure the vertical distance from the tip of your pinky to the tip of your thumb. In order to get a better measure of this, do it 3 times, relaxing your hand between times, and record the average.

b = ________ in

Task 2. Measuring length a.

Hold your hand in the gaging position and have your partner measure the horizontal distance from your eyeball (please don't actually touch the measuring device to your partner's eyeball!!). In order to get a better measure of this, do it 3 times, relaxing your hand and dropping your arm to your side in-between times, and record the average.

a = ________ in

Task 3. Calculating the height of the object per pace based on this ratio.

Given the values of a and b you found above and your pace length, you should be able to calculate a ratio of units of height of object per paces of horizontal length to object.

_______________ ft height / my pace

______________ m height / my pace

Task 4. Height of the tree.

Using just your sighting and pacing techniques, measure the height of the first tree to the West of the main Estabrook entrance (West is towards the stadium).

tree height in ft _____________

tree height in m ______________

Analysis

1) let’s say that instead of just holding out your pinkie and thumb you held a 1-ft ruler in your hand to establish b.

a) How would the height per pace change?

b) Would this make your answer better or worse, and why?

2) now suppose you used a yardstick instead of a 1-ft ruler to get b. Would your height measurements likely be better or worse than for the 1-ft ruler, and why?

3) now answer the same question but if you used a 12-ft long rod to get b.

4) what problems might you have with using this method to measure the height of Neyland Stadium?

5) the method was first laid out assuming a right triangle. How much difference will it make if the bottom length (A) is not horizontal, but rather slopes upward or downward?

Lab. Worksheet 4.3

Moments

EF101 – Engineering Approach to Physical Phenomena

Fall, 1997

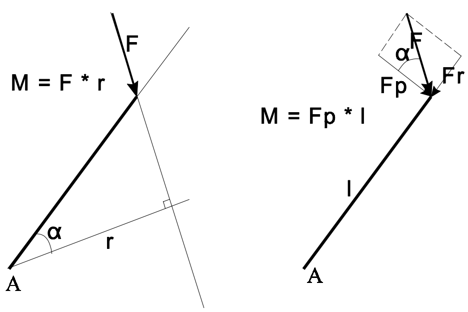
Objectives:

- to develop an understanding for the concepts and uses of moments

Background

So far we have been dealing with forces, regardless of where they are applied. We now bring in the recognition that how an object responds to a force depends not only on how big the applied forces are, but also on where those forces are applied on an object. For example, the up-and-down forces can be perfectly balanced, and the side-to-side forces can be perfectly balanced, but applying those forces can still cause the body to spin like a top.

Each force acting on a body will cause a tendency for that body to spin, and only when these tendencies are canceled out will the body truly not accelerate. The tendency to spin about some point caused by applying a force somewhere on the body is called the moment of that force about the point. It turns out that it doesn’t matter what point we choose to sum the moments around; if the object is not going to begin spinning the total sum of the moments must be zero.



The moment is defined as the magnitude of the force times the perpendicular distance from the summation point to the line of application of the force. The moment is arbitrarily given a sign based on the “right-hand” rule, which says that a moment causing the object to spin counter-clockwise is considered positive, while a moment causing the object to spin clockwise is considered negative. This arbitrary convention is used so that moments in opposite directions will cancel out mathematically.

One of the toughest things about using moments is trying to figure out the moment arm, which is the distance over which the force is acting. There are really two ways of looking at this, demonstrated by the figure. The first is to deal with the original force and to find the perpendicular distance to the line of action of the force. This approach is shown on the left part of the figure. The second approach is to break the force itself into two components, one acting through the summation point (A) and therefore contributing no moment, and the other acting perpendicular to that and therefore having a moment arm equal to the distance from the A to the point of action of the force (that distance is l in the right-side diagram). Note that these give the same result, since on the left side we have $r = l \cos(\alpha)$ so $M = F * r = F * l \cos(\alpha)$, while on the right-side diagram we have $Fp = F \cos(\alpha)$, so $M = Fp * l = F \cos(\alpha) * l$, which is the same.

Procedure

Task 1.

Using a step-ladder with 100 lbs. on top, and knowing the weight of the ladder:

a) take the measurements necessary to calculate the forces on the ladder's legs;

b) in your response, use appropriate free-body diagrams and calculations to determine the force on the ladder's front legs;

c) use the scale to measure this force, and compare it to your calculations.

Task 2.

Using a piece of wood with caster attached to one end:

a) take all measurements necessary to calculate the friction force with the floor for two different angles of the wood leaning with the caster against the wall;

b) find the angle at which the wood will no longer stand upright, and calculate the friction force of wood against the floor at this angle;

c) turn the wood over so that the wood (and not the caster) is touching the wall, and find the angle at which the wood begins to slide. Why is this different from the angle with the caster touching? Can you calculate the friction force between the wood and the floor at this point?

<u>Task 3.</u>

Using the spring scale attached to the wall:

a) Holding the string fairly taut, stand as straight as possible with your feet together.

b) lean back far enough to get readings of 30, 40, and 50 lbs. on the scale. At each of the readings, have your partner measure the angle that your body is making with the floor.

c) for each of these readings, knowing your weight, and assuming that your body is perfectly straight along the measured angle, calculate the location of your center of mass.

Analysis

<u>All Tasks</u>

Be prepared to explain, with appropriate FBD's and vector descriptions and calculations, the results from all 3 tasks.

<u>Task 3.</u>

For this task, you will need to show the calculations necessary to find the CG for the person

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Lab. Worksheet 5.2

Static Equilibrium

EF101 – Engineering Approach to Physical Phenomena

Fall, 1997

Objectives:

- to understand static equilibria and the use of this tool in solving problems

Background

We have now developed all the tools necessary to solve problems where systems are in static equilibrium. In these cases we know that there is no acceleration, so by F = m * a there is no net force. In these cases we can say that $\sum F_x = 0$ and $\sum F_y = 0$ (and, if we were dealing with 3-D, $\sum F_z = 0$). If the situation is truly in static equilibrium we must not only have no acceleration in the x or y direction (or the z-direction), but we must also have no net tendency for the object to spin, or to undergo what we call angular acceleration. If that is true, then we must also have $\sum M = 0$, where this is the summation of moments about any point.

In most of the problems we're working we will thus have 3 tools, or 3 equations. From our basic rules of math this means that we can solve for 3 unknowns, so there are some situations with more than 3 unknowns where we can't come up with a solution. An example was our wood with no caster leaning against a wall, where we don't know the contact forces of the earth and the wall on the ladder, nor the friction forces of the earth and wall on the ladder, yielding 4 unknown forces. In this case we can sometimes makes some assumptions, like assuming some friction coefficient for the friction forces, but without some additional information like this the problem cannot be solved.

In general, in solving these problems we begin by summing moments about some point so as to leave only one unknown force or distance. We do this by choosing the summation point so that the lines of action of one or more forces act directly through the summation point, thus contributing no moment and dropping out of the equation. We can then use the other summation equations as necessary to give us additional results.

Dynamic situations are really very similar, except that one or more of the summations ($\sum F_x$, $\sum F_y$, $\sum M$) no longer sums to zero, and we are forced to bring in some of our equations of motion (F = m * a, etc.) in order to solve the problem. We will learn more in the next lecture about what happens when we don't have $\sum M = 0$, and have to come up with an equation of motion for spinning or twisting.

Procedure

In each of the 3 following tasks you will be asked to explain a situation involving forces and moments in static equilibrium. In each of your explanations be sure to concentrate on how the situation relates to the concepts of forces and moments, using ideas presented in the lectures and the homework.

Task 1.

Explain how the large mechanical platform scale works, taking whatever measurements you think necessary, and phrasing your explanation in terms of forces and moments. Use as an example the situation in which you are weighing yourself.

Task 2.

a) Explain why a pulley makes the weight easier to lift. You don't have to pull as hard to lift the weight, but what is the trade-off?

b) If work is force times distance, do you do more work lifting the block one foot with your hand, or lifting it one foot using the pulleys? Explain

Task 3.

a) Explain how the board with a weight at one end can be in static equilibrium. Recall our earlier discussion of how forces cause an object to respond on a molecular level.

b) Take whatever measurements you feel necessary to be able to predict how the board would respond to a range of different weights, and show this graphically.

c) How would you expect the board to respond if you set it on edge rather than flat? Explain your answer in terms of forces and moments.

Task 4.

Using diagrams and whatever measurements are necessary, estimate the tension in the ligaments of the elbow joint when you lift a 10 lb weight in a "curl" motion (bending the arm at the elbow).

Analysis

All Tasks

Be prepared to explain, with appropriate FBD's and vector descriptions and calculations, the results from all 3 tasks.

Lab. Worksheet 6.1

Conservation of Energy

EF101 – Engineering Approach to Physical Phenomena

Fall, 1997

Objectives:

- to understand the various types of energy
- to be able to explain the conversion of energy from one form to another
- to be able to work with the common relationships for kinetic, potential, and elastic energy

Background

It has been said that all engineers work with energy, and that the only difference between the disciplines is in the forms of energy and the mechanism of the conversion between the forms.

If we look at a single object, it can have any or all of many different forms of energy, including the following: thermal (heat), field (gravitational, magnetic, electrostatic), motion (both translational and rotational), elastic (stretching of molecules), chemical, electrical, and others (including light energy, sound waves, etc.). The total energy level of any object is the sum of all these individual forms.

In general, we can change the energy level of our object (or our control volume) in one of three ways. The first is by moving mass into or out of the object. This can get very complicated, and the energy within the object then depends on what was in the object before and the amount and characteristics of what you're putting into it. We will ignore this for the time-being, and will concentrate on systems where no mass moves into or out of the object.

The second way of changing an object's energy is by allowing heat to flow into or out of the object. We will say that heat flowing into an object will increase its energy level, so that heat flowing out will decrease that level. Finally, the third way of changing an object's energy is by doing work on the object, where work is defined as applying a force to the object and causing it to accelerate and move.

If we assume that there is no mass movement into or out of the object (or the control volume), we thus define the object's energy change as $\Delta E = \Delta E_{chem} + \Delta E_{elas} + \Delta E_{motion, rot} + \Delta E_{motion, trans} + \Delta E_{therm} + \Delta E_{field, grav} + \Delta E_{field, mag} + ... = W + Q$, where W is work and Q is heat transfer. Positive work or heat transfer increase the object's energy, while negative values decrease it. Now let's look at a few of these terms in more detail.

We start with work, which is related to the force which accelerates the object and how the object responds to that force. If we look at a force pulling a box across a floor (see diagram below), we see that the actual work done is dependent not only on the force and the amount of movement, but also how the direction of the force is related to the direction of the movement. If we pull straight up on the box and the upward force is less than the box's weight we will reduce the contact force of the floor on the box, but will do no useful work moving the box across the floor. If the force pulls directly in the direction that the box moves the force does the most useful work. The work is therefore $W = F \bullet \Delta s = F * \Delta s * \cos(\theta)$, where F is the size of the force, Δs is the distance the object moves, and θ is the angle between the direction of the force and the direction of motion. Note the $F \bullet \Delta s$, which is read as "F dot s". This is not the same as $F * \Delta s$ (F times Δs), but is rather called the "dot product". In general, $A \bullet B = A * B * \cos(\theta)$, where A and B are any two vectors. The dot product gives a result that is not a vector, but is just a magnitude with no direction (a scalar).

Let's look at a weight (weight = mass * a_g) that is being lifted over some distance Δh by some force. The force required to lift a weight is just a tiny bit bigger than the weight, so $F = m * a_g$. The work done is therefore $W = F \bullet \Delta s = F * \Delta s * \cos(\theta)$, but in this case $\Delta s = \Delta h$ and F is in the same direction as Δh, so $W = m * a_g * \Delta h$. The only change in energy from lifting the weight is $\Delta E_{field, grav}$ (you're moving the weight further away from the center of the earth), and there is no heat loss or gain ($Q = 0$), so $\Delta E_{field,grav} = W = m * a_g * \Delta h$. We will often see this form ($m * a_g * \Delta h$) when we are dealing with things being raised or lowered, and this form of energy is often given the name "potential energy".

In looking at the energy of an object in motion we go back to our basic motion equations. We start with the definition of velocity $v_{avg} = \Delta s / \Delta t$, and also $v_{avg} = (v_1 + v_2) / 2$. We set these equal and solve for Δt. We then take the definition of acceleration $a_{avg} = \Delta v / \Delta t$ and solve this for Δt as well. We can set these equal to get $\Delta v(v_1 + v_2) / 2 = a * \Delta s$. We then take the force relationship $F = m * a$, solve this for a, and put it into the relationship above to get $m * \Delta v (v_1 + v_2) / 2 = F * \Delta s$. We can then substitute $W = F * \Delta s$ and $\Delta v = v_2 - v_1$ to get $m (v_1 + v_2) (v_2 - v_1) / 2 = W$. If we multiply this out and separate the terms we can get $W = ½ m v_2^2 - ½ m v_1^2$. Since the only change in the energy of the object has been in translational motion, we get that $W = \Delta E_{motion, trans} = ½ m v_2^2 - ½ m v_1^2$. We often call this form of energy "kinetic energy". By the way, we could get the rotational motion forms of this relationship just like we got the translational forms, and we would end up with $W = \Delta E_{motion, rot} = ½ I \omega_2^2 - ½ I \omega_1^2$, where I is the moment of inertia and ω is the rotational velocity.

We will also work with ΔE_{elas}. This is usually done by assuming that the force required to compress (or stretch) a spring or other elastic material is a function of the spring itself and of how far you're trying to stretch it. This is defined mathematically as $F = k * \Delta L$, where k is a property of the elastic material and is called the "spring constant", and ΔL is the amount it has been stretched from its "normal" state. When we look at the work used to stretch or compress the spring ($W = F * \Delta L$), we have to take into account that the force changes as ΔL gets bigger. The work used to stretch or compress the spring is therefore $W = ½ k (\Delta L)^2$, which means that $E_{elas} = W = ½ k (\Delta L)^2$.

Procedure

Task 1.

1) Take the bungee cord with the attached weight holder. Measure the height of the bottom of the holder above the floor. Now add 100g of weights to the holder, and measure the distance that the holder drops. What is happening here is that we are taking the $\Delta E_{field, grav}$ of the weights and converting it into ΔE_{elas} in the bungee cord. Use the definitions of $\Delta E_{field, grav}$ and ΔE_{elas} to determine the spring constant k of the bungee cord.
2) Now add another 100g of weights to the holder, and use the full stretch over the 200g to once again calculate the value of k.

Task 2.

1) Using the small ramp, roll a tennis ball over the course and measure the time required for the ball to move between the 20-ft and 25-ft markings.
2) Using this time and distance (5 ft), calculate the average velocity of the ball in this section.
3) Calculate the $E_{motion, trans}$ for the ball as it rolls through this section.
4) Calculate the $E_{field, grav}$ for the ball before it is dropped.
5) Calculate the change in energy, which will be the work done on the ball by friction.
6) Knowing that work is force times distance, calculate the average friction force on the ball from the time it is dropped in the ramp.

Task 3.

1) Drop a tennis ball from waist height, and measure the height to which the ball bounces back up.
2) Calculate the energy level of the ball before it is dropped, and when it is at the top of its first bounce.
3) Calculate the percentage energy loss in the bounce.
4) Calculate the velocity of the ball just before it hits the ground.
5) Calculate the velocity of the ball just after it leaves the ground, assuming that the total energy loss occurs in the bounce itself (the loss of energy to air friction is assumed to be negligible).

Analysis

1) Show that you understand the ideas behind the calculation of $\Delta E_{\text{field, grav}}$, $\Delta E_{\text{motion, trans}}$, and ΔE_{elas}.
2) In Task 1, how much difference was there in the values of k calculated using the two different weights? If there were a major difference, what would it mean?
3) We have already dealt with an elastic material (though you probably don't normally think of it as that) when we put weights on the end of a board and measured its deflection. Would you guess that the wood's "spring constant" was linear over the range that we measured? Why or why not?
4) In Task 3 you calculated an energy loss. Where did that energy go?