Session: 1761

Synthesizing Liberal Arts Physics

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Introduction

This paper presents several exercises for use in courses for non-science students who are fulfilling a general education science requirement. Each exercise requires students to use fundamental concepts to design something new. In this manner, the exercises force the students to move from the lower levels of Bloom's Taxonomy to the synthesis and judgment levels[1]. Although these activities were used in a course for non-science students some may be useful in engineering courses as well.

Course Description, Physics 105, How Things Work, Elizabethtown College, Pennsylvania:

> This course will introduce students to concepts in physics as relates to commonly used technology and processes experienced in daily life. As students become familiar and comfortable with science and technology, they will understand the predictable nature of the universe and dispel the "magic" of science and technology. Possible topics include: Motion (skating), Mechanics (amusement parks), Electronics (computer), Electromagnetic Waves (radio), Fluids (siphon, vacuum cleaner), Heat (furnace, air conditioning), Resonance (clocks, musical instruments), Electric Forces (air cleaners, copiers, maglev trains), Electrodynamics (flashlight, tape recorder), Light (lasers, paint), or Optics (cameras, telescopes, microscopes). The course will include a two-hour laboratory component each week.

The text How Things Work by Louis Bloomfield covers each of these topics and numerous others and was selected for the course[2]. The text was well received by the students: they enjoyed reading it and found most of the explanations easy to follow. The text contains numerous exercises for developing the lower three levels of Blooms Taxonomy: knowledge, comprehension, and application. Many of the exercises and case studies require the students to apply material in both presented and new situations. For example, lift is explained in the fluid mechanics chapter through discussion of spinning balls, Frisbees and airplane wings, and the exercises include questions such as:

> "Why does an airplane have a "flight ceiling," a maximum altitude above which it can't obtain enough lift to balance the downward force of gravity?"

> and "A hurricane or gale force wind can lift the roof off a house, even when the roof has no exposed eaves. How can wind blowing across a roof produce an upward force on it?"[2].

The goal of this course was to address a few aspects of technical literacy: to understand and use mathematics and science, understand the working of technological devices, and to apply mathematics and physical principles to solve novel problems[3]. I desire to have the students learn how to use the ideas and theories to solve realistic problems and design "real" devices. These activities reinforce the idea that students can actually do something useful with what they are learning. I also want to expose students to engineering problem-solving techniques, since I believe students in all disciplines can benefit from learning these skills.

Several textbook exercises involve using concepts learned to synthesize something new or make critical judgments regarding a solution. For example in the same chapter on fluid mechanics one problem asks:

> "If you want the metal tubing in your bicycle to experience as little drag as possible while you're riding in a race, is cylindrical tubing the best shape? How should it be shaped?"[2].

However, more of these types of exercises and inclusion of some which are more open-ended would be a valuable tool for moving the students to the synthesis and judgment levels of Bloom's Taxonomy.

The inclusion of such exercises in weekly assignments and exams should help the students toward a deeper level of understanding of the topics studied. Additionally, the problems require the students to develop some more advanced problem solving skills: breaking complicated problems into manageable pieces, making and justifying appropriate assumptions and design decisions, and making judgments as to the reasonableness of a finished design.

In the following sections of this paper, several problems are included from the first offering of this course (Fall 2003), from homework assignments, laboratory exercises and exam questions. Then the discussion and conclusions section describes overall student performance on these exercises and includes suggestions for incorporation into courses designed for non-science majors.

Homework Exercises

Assignments typically included one open-ended design problem which was to be done as a team with their lab partner(s) along with a set of textbook exercises targeting the lower levels of Bloom. The open-ended problems counted for 10% of their homework score. At the end of the semester, I dropped their three lowest scores on these problems. With these problems, I'm not so concerned with errors in the calculations and such, but more with the process of attacking them: Are students engaged in the problem making decisions, justifying them and analyzing the resulting complete design? I am not expecting a detailed analysis, but do expect an application of the basic "Important Laws and Equations" included in the text. Provided here are the problems used for the first 10 chapters of the Bloomfield text along with possible solutions and some comments:

Chapter 1 covers the laws of motion and discusses ramps as an application:

Design a wheel chair access ramp for a private home. The front porch is 1 m above the grade of the front yard and is in the center of the house. The front yard is 10 m wide and 10 m deep. Explain your decisions in this design. This is to be a conceptual design and can be explained in one paragraph. All I'm looking for is the slope you are going to use for the ramp (and why?). Then how it will fit in the space available (you may need it to switch back and forth a few times).

Solution: I would estimate that with each hand I can easily provide 5 extra pounds of force to the rims of the wheels of my wheelchair. This estimate was obtained by repeatedly lifting a 5 lb mass without noticeable fatigue. Next, I estimate the total mass of myself and a wheel chair to be approximately 200 lbs. Based on these estimates I would need a ramp pitch of 200:10 or 20:1. So, to raise the chair 1 meter, I will need a ramp that is 20 meters long. To achieve this distance I will extend the porch toward the driveway side of the house creating a 2 meter long landing (this will allow you to enter the house from a level grade). Each of the ramps will be 1 meter wide. Then I will run a ramp back toward the opposite side of the house 6 meters and then back toward the driveway 14 meters. Allowing 1 extra meter at each turnaround point (this 1 x 2 meters area should be ample for pivoting the chair around), this design will use the full width of the yard. The access point will be at the driveway which should be convenient.

Discussion: I did not record a grade for this first problem but rather only gave feedback on each submitted solution and encouraged them to review the posted solution, with a strong emphasis that for these types of problems there is not one right answer but any reasonable solution that meets any criteria is acceptable.

Chapter 2 covers additional topics on the laws of motion including energy and levers:

Design your own fair contest – the strength tester. Design the mallet (how heavy and how long of a handle); design the mechanism (I suggest a lever) you hit with the mallet to send the lead mass up toward the bell at the top of the tower (how long should each side of the lever be); design the lead mass and the tower (how heavy should the mass be and how tall should the tower be). Again, don't worry about all the details, but briefly explain each of your design decisions.

Solution: You've seen these before, the mallet should be heavy, but it should be possible for one to lift it over his or her head, let's say 15 kg (30 lbs). Also, 0.7 meters (just over 2 feet) seems like a reasonable length for the handle. With these established we can design the rest of the device. Assuming a tall man can lift the head of the mallet to a height of 3 m the mallet would have a potential energy of mgh=450 J. Then assuming an average downward force of 250 N (about 50 lbs), the customer would give the mallet an additional $F \cdot d = 750$ J of energy on the way down. Therefore, the mallet has 450 J + 750 J = 1200 J of energy upon striking the lever.

We will use a lever of a total length of 1 m with the pivot point at the center. Now, the mallet will still have some energy when striking the ground after launching the lead mass. We'll assume that ½ of the energy of the mallet can be transferred to the lead mass. (This may not be a great estimate, but we know at least some of the energy must be lost.) Then, the lead mass (let's make this 5 kg) has 600 J of kinetic energy at the bottom of the tower. This means, neglecting friction, the mass will be able to rise to a height of 12 m (h=Energy/(mg)). Since there will be some friction in the tower we'll make the tower this tall (about 40 feet), and it should be significantly difficult, but not impossible, to win the grand prize.

Score	Typical Submission
5	*The student(s) did a design, but didn't explain anything.*
6	*The student(s) had significant errors in their explanations or a very minimal explanation.*
7	*The student(s) had a general explanation of the decisions, but no specifics.*
8	*The student(s) suggested how to determine the specifics of the design but did not actually make the calculations.*
9	*The design had one or more minor errors.*
10	*A complete and reasonable design was submitted.*

Table 1: Typical grading scheme for the design problems.

Discussion: On this, the first graded problem, I used the grading scheme shown in Table 1. No one actually did the full analysis. Doing the calculations is an important part of these problems, because it is in this part of the problem that the students really need to move into the judgment level of Bloom. Their initial assumptions and design decisions will lead to a final design that is either feasible or not and they should pass judgment on this and change the design if necessary.

Chapter 3 covers mechanical objects including bicycles:

Find a friend with a bike with five or more speeds and determine the gear ratio of each of at least 5 speeds on the bike. Explain what these speeds mean (how hard do you have to push on the pedal to make the bike experience a particular acceleration?) and why choose one speed over another.

Solution: The easiest way to do this is to count the teeth on each of the gears. If the front gear (attached to the pedals) has 50 teeth and the back gear (attached to the wheel) has 10 teeth the gear ratio is 5:1 and the back wheel will rotate 5 times for every turn of the pedals. The lower this ratio the "easier" it is to pedal at low speeds so low ratios are good for starting out or climbing hills. The greater the ratio the fewer rotations of the pedals per meter of travel making these gears better for traveling at higher rates of speeds.

Discussion: I felt this problem was more straight-forward than the previous two – everything they needed to know to complete the problem was easily available in the text or on the web.

Chapter 7 included the topic of musical instruments:
Chapter 7 was included prior to chapter 4 in the course and is therefore included here out of sequence.

You are to design a one string banjo that will produce the seven notes listed as the basic scale for western music (listed on page 240 of your text: A_4, B_4, $C^{\#}_5$, ... Select the string properties (mass, length, and tension). Then determine where to place the frets to produce these notes. You should assume the tension is constant and use the formulas from the lab to determine these positions. Please see me if you need help!

Solution: The lowest pitch is the A_4 with a frequency of 440 Hz. I will design my string to play that note (as its fundamental mode). About ¾ of a meter seems like a reasonable length for my banjo. I will be able to easily reach the entire length of the string for fingering and plucking. Also, the string we used in lab should give me a reasonable mass/length ratio and that was about 0.0004kg/m. Therefore to produce a fundamental vibration of 440 Hz I need a tension of:

$$\tau = \frac{4\mu f^2 L^2}{n^2} = \frac{4(0.0004)440^2 0.75^2}{1^2} = 174 \text{ N (about 40 lbs)}$$

This sounds reasonable, so I will proceed to place the frets. The frets will allow me to change the effective length of the string without changing the tension. I can solve the above relationship for the required length to produce each note (Table 2):

$$L^2 = \frac{\tau n^2}{4\mu f^2}$$

Frequency	**length**
440*(9/8) = 495 Hz	0.67 m
440*(5/4) = 550 Hz	0.60 m
440*(4/3) = 587 Hz	0.56 m
440*(3/2) = 660 Hz	0.50 m
440*(5/3) = 733 Hz	0.45 m
440*(15/8) = 825 Hz	0.40 m

Table 2: Design parameters for the one string banjo problem.

Discussion: The equations above were used by the students in a laboratory assignment. With increased encouragement to see me for help on this problem, several students did. Their performance increased sharply and for the most part, these students then continued to perform well on the problems from that point forward. (As indicated above, this chapter was actually the fourth chapter covered, so this was only the third graded problem.) Overall those that submitted a solution to this problem did quite well: the average score was 84%. The form of the help given was simply how to start to use the equation (they had determined that they need to use the relationships from the lab) when they had too many unknown variables. The students struggled with making the necessary design decisions and appropriate assumptions. However, just over 50% of the students submitted solutions to this problem, and after this assignment I had to distribute grade sheets to illustrate how not doing these assignments hurt their performance in the class.

Chapter 4 covers fluid statics including balloons:

I heard of a guy that disrupted air traffic control patterns by tying helium-filled balloons to a lawn chair and taking flight. I'm not sure if the story is true but it is amusing to think about. You are to design your own flyer based on this concept. Things to consider: how to go up, how to level off for steady height flight, and how to get back down alive. Again, ask me if you need help!

Solution: To achieve lift I will need a buoyant force greater than the weight of me, the chair, the mass of any balloons, and any other supplies I may need. Assuming a total weight of 1000 N for all of this (I weight about 750 N, so this is quite reasonable), I can calculate how much air I will have to displace with helium. From our text helium can be assumed to weigh 14% as much as air. To hold 1000 N in equilibrium in air I will need to displace approximately 100kg more air than the mass of the helium I displace it with. Each m^3 of air displaces 1.08 kg more air than the mass of helium taking its place. So I need 93 m^3 of helium for level flight. That's a lot of Mylar balloons from the Hallmark store – I'd estimate at least 3000 (each one is probably less than 1/30 of a m^3 (a 1 foot cube balloon would be about 1/30 of a m^3). I don't want to go up very fast so I will say I will accelerate at 0.1 m/s^2 (neglecting air resistance it would take me about 45 seconds to reach a height of 100 meters). I need 10 N of buoyant force for this acceleration (an additional 300 balloons). I will put a net around 2900 balloons, a second net around the 300 and a third net around the last 100 balloons. When I get close to my desired height I will cut the line to the 300 balloons and stop my rise (with the help of air resistance) and when I want to drift back down I will release the 100 balloon net to begin my descent.

Discussion: After calling attention to how attempting these problems can help their performance in the class, the number of students submitting solutions did increase sharply to over 70%. This was done without a drop-off in the quality of the solutions submitted, with the average score of 80%.

Chapter 5 covers fluid dynamics and flow in pipes:

Paul of Papa Paul's Pizza and Pasta Palace has hired you to design a state of the art olive oil delivery system for his restaurant. He wants to place a large storage tank of oil on the roof (5 meters above the ground) of the restaurant near the front of the building, so that he can paint the famous interlocking penta-P logo on the side of the tank. The kitchen is at the rear of the building (25 meters from the front door). The system should deliver oil at a reasonable rate with the valve fully open in the kitchen.

Solution: I will assume that the olive oil should be dispensed at a height of 1.5 meters above the ground (approximately the height of a typical counter). We will construct the tank so that the typical level of the oil in the tank is 4 meters above the surface of the roof. We will route the pipe straight down into the roof and to a height 1 meter below the height of the roof so that the pipe can run above the ceiling inside (the pressure in the master pipe will then be the density of the oil times g times the height of 5 meters or 45kPa (gage pressure – difference between the oil pressure and atmospheric). We will assume this pressure to calculate the flow rate. We will assume 1 liter per minute is a reasonable rate.

$$flowrate = 1000\text{cm}^3/60\text{s} = 0.000017\text{m}^3/\text{s} = \frac{\pi\left(45{,}000\ \text{Pa}\right)D^4}{128\left(25\text{m}+5\text{m}+2.5\text{m}\right)0.084\text{Pa}\cdot\text{s}}$$

$$D^4 = 4.1 \text{ x } 10^{-8}\ \text{m}^4$$

$$D = 1.4\ \text{cm}$$

Our pipes need to be 1.4 cm in diameter (0.55 inches).

Discussion: Again, students did well on this assignment with an average score of 78%, and over 70% of the students submitting solutions.

Chapter 6 covers heat transfer and thermodynamics:

You are to design a simple heating system (we are oversimplifying as usual, but the principle is correct). You are heating a 2.5 meter by 3 meter by 2.5 meter office. There is a single door in one wall and a window in the opposite wall. For this kind of heating system you heat water into steam and then pass the steam through a radiator where it condenses back into a liquid before returning to be heated again. When the water cools down and condenses it heats the walls of the radiator. (Energy is transferred from the hot water into the radiator.) Let's assume that your radiator is heated to a constant temperature of 50ºC (while on). You should design your radiator out of standard 2.5 cm diameter pipe. What is the surface area of a one meter pipe with this diameter? You can construct any arrangement (you can zigzag the pipe if you want) you feel is appropriate. By what means will the all the air in the room become heated (how will the whole room reach the desired temperature)? To heat the room from 40ºF (4ºC) to 72ºF (22ºC) should take a maximum of 25 minutes. Every kilogram of air has 511kJ of energy at 40ºF and 530kJ of energy at 72ºF. How many kg of air are there in the room (1 m^3 of air has a mass of 1.25 kg)? How much energy needs to be transferred into the room? Power is change in energy divided by time. When the correct temperature is reached the thermostat will shut off the water flow and the heat supply. Where should the thermostat be positioned?

Note: what your text fails to fully explain is that the room is also transferring radiation into the radiator so that the net power transfer is actually:

$$P = e\cdot\sigma\cdot A\cdot\left(T^4 - T_0^4\right)$$

where T_0 is the temperature of the surroundings (room). Temperatures must be expresses d in Kelvin.

Solution: The thermal energy will be transferred throughout the room by convection. The heat will leave the radiator primarily by radiation. The thermostat should be positioned on the wall opposite the radiator, to ensure the whole room has reached the desired temperature.

We will build the coil out of 2.5 cm pipe. The surface area of this coil will be

$$A = 2\pi Rl = 2\pi(0.025\text{m})l = (0.0785\text{m})l$$

where l is the length of the radiator pipe. Assuming the worst case, I will assume the room is empty and therefore contains

$$M_{air} = \rho_{air}V = (1.25\text{kg/m}^3)\cdot[(2.5\text{m})(2.5\text{m})(3.0\text{m})] = 23.4\text{kg}$$

of air and therefore we must transfer

$$23.4\text{kg}(530\text{kJ/kg} - 511\text{kJ/kg}) = 445\text{kJ}$$

of energy into the room.

I will use black piping for an emissivity of 1. Then, I will assume that ½ the area of the pipe will transfer heat efficiently (the other half will be radiating into a neighboring coil). My coil will zigzag back and forth several times with vertical pipes that are 1.5 meters long. For my design I will assume the temperature of the surroundings are 72ºF (again this is the conservative estimate).

$$P = \frac{445,000\text{J}}{25\cdot 60\text{s}} = e\cdot\sigma\cdot A\cdot(T^4 - T_0^4) = 1\cdot\sigma\cdot\frac{.0785l}{2}\cdot(323^4 - 295^4)$$

$$(7.37)l = 297$$

$$l = 40\text{m}$$

So I need 40 m of pipe. This means I need 27 1.5m sections. If I space the pipes with 2.5 cm between each pipe in the zigzag pattern the grid will be 5x27cm wide or 1.35 m. So the entire radiator will be 1.5 m tall and 1.35 m wide. This should heat the room in less than 25 minutes.

To calculate the actual time to heat the room, I used Excel to calculate the heat transfer second by second, to account for the changing temperature, and the actual pipe length of 40.5m, and the room will reach 72ºF(295K) in about 20 minutes (Figure 1). I did not expect the students to perform this type of analysis but it was included for their information.

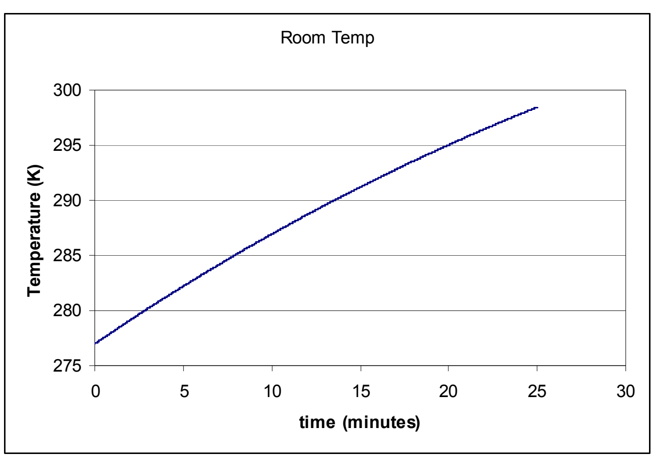

Figure 1: Room temperature as a function of time for the heat transfer problem.

Discussion: This problem was rather difficult for this level. However, many students did do well on the problem by asking me appropriate questions. I was always very supportive on these problems, which were very challenging for many of the students, strongly encouraging students to ask questions and to get help from me or peer tutors. We used Blackboard heavily for this course and these problems were frequent topics on the discussion board. Depending upon the question, I would reply to questions privately or post the question and answer on Blackboard.

Chapter 8 discusses electrostatic forces:

Do the experiment "Moving Water Without Touching It" found at the start of the chapter. Then explain how you could use this concept to construct a device to direct a flow of water (without touching the stream of water) into 1 of 9 cups, where an operator could select which cup to fill at a given time.

Solution: You should have done the experiments suggested in the text. The water is attracted toward the charged comb because of electrostatic induction (the same way a balloon clings to a neutral wall). Conductors do not hold separated charges since the electrons quickly move to toward the positive charges in the material and become neutral. Objects toward the extremes of the triboelectric series chart in the lecture slides will work the best.

If you have two combs positioned 90° apart you can manipulate the water into a particular cup. Arrange the cups in a 3 by 3 grid and then with the water falling straight into a cup in one of the corners, say the NW corner. Then by bringing the comb on the east side of the grid toward the steam of water you can direct the water into the center row of the cups and by bringing it closer the water can be drawn into the east most cups. A comb positioned to the south of the cups can do the same thing to direct the water into the center column or into the south most column of cups.

Discussion: This simple but not very practical design problem did set the stage for our discussion of the steering system guiding the electron beam in a television tube a couple of weeks later.

Chapter 9 covered electromagnetism and power:

Design a magnet for use at a scrap yard for lifting cars. The holding force of a horseshoe electromagnet is

$F = 397{,}840\, B^2 A$ (in Newtons)

Where A is the contact area (iron core) for the magnet in m^2 and

$B = \mu_0 \frac{N}{L} I$ (In Tesla)

and $\mu_0 = 4\pi \times 10^{-7}$ T·m/A, N is the number of turns of wire, L is the length of the magnet and I is the current through the coil.

Assume the resistance of the copper wire is 3×10^{-4} ohms per meter of length. You should design a magnet, and then determine the power usage required to hold a 1500 kg car.

Start working on this problem early and post questions on blackboard. I will respond to these questions as they come up. I will help you do this problem, but you need to ask for help!

We need to support a force of 1500kg (9.8m/s^2)=14,700 N. Let's say the total area of our magnet's contact area is 0.5 meters on a side for an area of 0.25m^2. Therefore from the first equation B must be 0.148 T

If I use wire with a cross-sectional diameter of 1.5 mm (this is 14 AWG wire), I can fit 667 coils per layer per meter and if I allow another .1 meters of thickness of the windings I will have 667 x 67 = 44,700 total turns per meter of magnet length.

Then my current will have to be 2.6 Amps. The power usage will be the current squared times the resistance of the wire. The resistance will be 0.01 ohms per meter (the value I gave you was for 0 gage wire which has a 2.1 mm diameter – but it would be ok if you used that number).

If my magnet is 1 meter long I will have approximately 44,700 x 4 x (.25+.05+.05) = 62,600 meters of wire with a total resistance of 626 ohms. Therefore my power usage would be (2.6)^2 x 626 = 4.2 kW (or 4,200 J/s).

Chapter 10 included computer logic:

Design a device to add two 1 bit numbers. Construct your device using inverters and NAND gates. The device should take two one bit inputs and output their sum. The following table summarizes what your device should do (Table 3):

Inputs		*Output*
A	*B*	
0	*0*	*00*
0	*1*	*01*
1	*0*	*01*
1	*1*	*10*

Table 3: Desired output for computer logic problem.

One possible solution that produces the desired output is shown in figure 2.

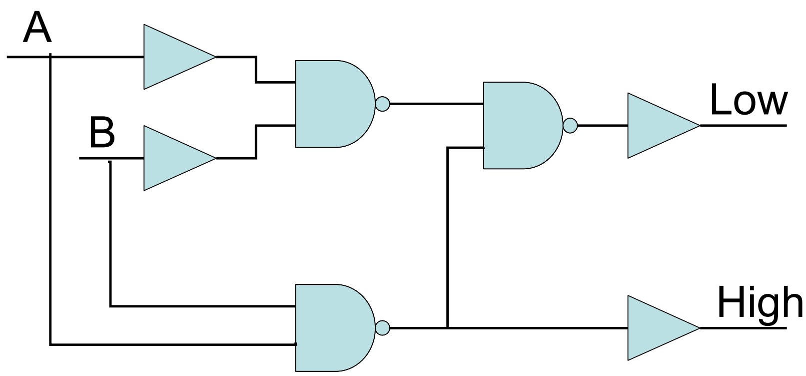

Figure 2: Possible solution to the computer logic problem.

Laboratory exercises:

Five of the 12 labs required the students to design small experiments to test a stated hypothesis. For example, in the first lab the students were able to use motion sensors and a computer based capture package (Data Studio ® PASCO) to test three hypotheses regarding the relationships between position, velocity and acceleration.:

Hypothesis 1: Velocity is the slope of the position plotted against time.
Hypothesis 2: Acceleration is the slope of velocity plotted against time.
Hypothesis 3: Acceleration can be non-zero when velocity is zero.

Rather than tell the students exactly how to do this type of experiment I prefer to show them how to use the equipment and then let them design, conduct and analyze an experiment to test a simple hypothesis. The students did well with these assignments although they did require an extensive level of coaching in the first couple of labs.

Figure 3: Test stand for the airfoil experiment. See the appendix for a brief description of the set-up. (These figures are 2M resolution and can be enlarged for better viewing).

Another laboratory was focused on synthesis and judgment, although it was not designed to test a particular hypothesis. The students had to design (cross section shape and angle of attack) and build an airfoil which was then tested in a homemade test jig (Figure 3) using PASCO force sensors to determine both the lift and drag over a 60 second time period and to calculate a lift to drag ratio, which was the primary outcome. Students were given instructions as to how to construct an airfoil from balsa wood and paper. The instructions included additional information on wing shape as a supplement to the material in their text. The students were encouraged to try a design even though they did not know *a priori* what would work best. With each group trying a different approach, in the end we would have a lot of data on different wing designs. The students' airfoils were constructed and tested over two 1.25 hour sessions. This is a revised version of a laboratory set-up John Krupczak has been using at Hope College[4]. Each team of 2-3 students then posted a sketch of their design on the board along with a summary of their results. All the students then needed to review all of the results to develop heuristics they could potentially use for building a future airfoil (Figure 4).

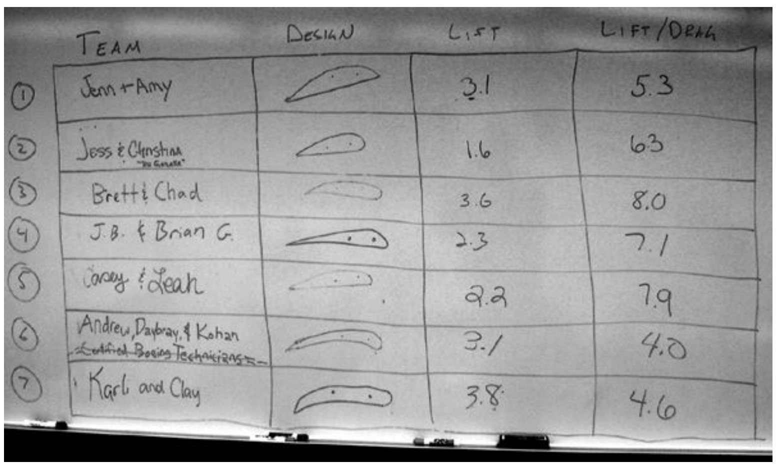

Figure 4: Student airfoil results from one section of the laboratory.

Most of the groups made very good observations discussing how the thinner and smoother (less steep front edge) designs performed better. They also found that with a more aggressive angle of attack the lift was generally improved, but with the expense of an increased drag often more than offsetting the gains in lift. They further noted the sharp inward bend of design 6 as shown in Figure 2 led to an increased drag; they suggested an increase in the turbulence in the air along the lower edge as a possible explanation. This laboratory was a very satisfying activity for the students.

Exams

Two exams also included design problems. These problems were considerably simpler than those from the homework (with lots of hints) due to time and resource constraints during an exam. The exams were closed book, but they were provided with all of the equations presented in the text.

First Exam: *Design the first two hills of a roller coaster such that the coaster will have a top speed of 40 m/s and the passengers will just barely come out of their seats at the crest of the* *second hill.* ***(a)*** *For the first hill you just need to give me one property which insures the desired velocity at the bottom of the hill.* ***(b)*** *For the second hill two properties are important to insure that the riders come out of their seats (additional hints: these properties control the velocity of the cart and the magnitude of the fictitious force pushing up on the rider. You want the support force between the seat and the passenger to be zero.) There is one correct answer for part a, and several correct answers for part b.*

Solution: For the first hill:

$$mgh = \tfrac{1}{2}mv^2 \rightarrow h = \frac{v^2}{2g} = 81.6 \text{ meters high}$$

Let's make the speed at the top of the second hill 20 m/s (you could pick anything less than 40 m/s), then

$$h = \frac{v^2}{2g} = 20.4 \text{ meters}$$

To get the person out of the seat, we need to design an appropriate radius of curvature such that the centripetal force has to equal the gravitational force

$$g = \frac{v^2}{R} \rightarrow R = \frac{v^2}{g} = 40.8 \text{ meters}$$

Second Exam: *You are to design a means to get a car (about 1500 kg; 1.8 m wide; 4.2 m long) across a lake. For the device you choose be specific about the dimensions of the design. (Densities of various substances: Air (20°C) – 1.25 kg/m^3, Air (500°C) – 0.50 kg/m^3, Helium – 0.175 kg/m^3, Water – 1000 kg/m^3.) Justify your design.*

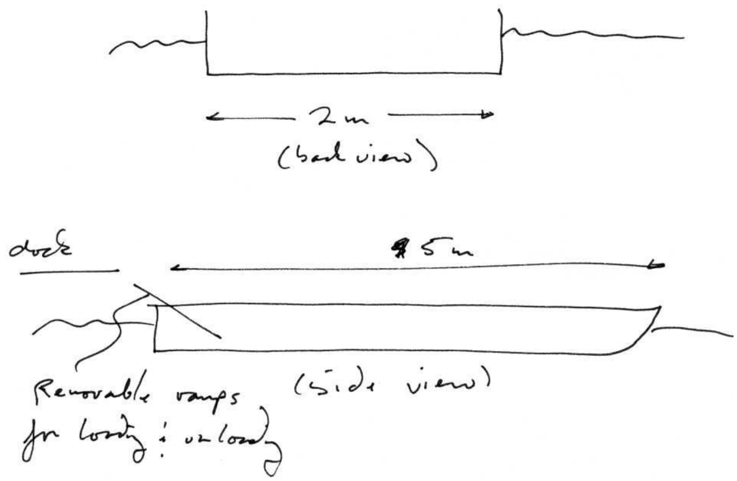

Figure 5: Boat sketch for second exam question example.

Solution: I will build a boat. The boat will have a flat bottom. It will be 5 m long and 2 m wide. The boat will have to be rather substantial structurally to support the weight of the car, so I will assume a mass of ½ that of the car to play it safe. So I need to support a total mass of 2250 kg; to do so my boat will displace 2.25 m^3 of water.

$$2 \times 5 \times h = 2.25$$
$$h = 0.225\text{m} = 22.5 \text{ cm}$$

The sides must be at least 22.5 cm high. I will make them 50 cm high to ensure small waves do not enter the boat and it is not swamped during loading. I'll use ramps and a dock for loading and unloading the car. Outboard motors will be used for propulsion.

Discussion and Conclusions

Most of the students in the course struggled even with exercises targeting the application level of Bloom's Taxonomy. Consultations with individual students indicated that many students felt challenged by trying to apply these very foreign (to them) physics concepts to situations not explicitly covered in class or in the text. This was reflected as well in student comments when asked about what aspects of the course they would like to see changed. Many commented that the exams were too difficult and indeed many did struggle on the exams. Many exam problems were at the application level. Despite these struggles and the fact that no students received higher than an A- in the course and the average grade was a B-, overall the students gave very high evaluations for the course and the instruction: excellence of course 4.6/5.0, excellence of teacher 4.9/5.0, and - of significance for this paper - learned to apply course material 4.5/5.

The students voiced discomfort with the design type problems described here. Only 75% (after drops) of the required problems were submitted and only a few students performed consistently well on these problems. The average score of the submitted problems of this type was approximately 68%. There were no trends toward improvement in the scores for these problems as the term progressed. However, when asked "Do you feel you made progress on being able to solve the open ended design problems (group problems)?" the students indicated that they felt that they did make progress (Table 4). Twenty-two of 29 students responded to the online survey which asked this question. The reasons for this probably include the difficulty of some of the problems which may have increased toward the end of the semester, increased loads in the students' major courses with term projects and such quickly approaching deadlines, perhaps the problem solving was more evenly shared between team members toward the end of the term so the progress was not evident in the scores, and probably most significantly the fact that I dropped the three lowest scores meant that the students that had been doing the best work on these problems could afford to skip three of the last four. For comparison the traditional assignments were submitted 98% of the time and the typical score was 89%. One student described the design problems as "impossible" and four other of 22 respondents (of 29 students in the course) to the same question as above asking what the students would change about the course voiced some level of frustration with these problems. Three of these were primarily with the logistics of the problems and the fourth did not provide any detail. The students were encouraged to work in groups on these problems (except on exams) and submit a single solution for the group, and group dynamics issues were listed as the problem with these exercises. Students expressed the usual difficulties of meeting times and one student doing the bulk of the assignment. I will continue to encourage group work on these assignments although I may use some class time to help the students get an early start on these problems. A common problem was also student groups who waited until the night before these assignments were due to even read the problem statement. Another student suggested that more time be spent in class explaining and teaching the process of doing these types of problems.

excellent progress	5%
good progress	32%
some progress	55%
no progress	9%

Table 4: Student responses to the question: Do you feel you made progress on being able to solve the open ended design problems (group problems)? Twenty-two of 29 students responded to the survey which included this question.

The last suggestion to spend more time teaching the students how to do these types of problems is right on the mark, and I will incorporate this in future offerings of the course. I did not anticipate the students need to be coached more extensively in this area prior to the first offering of the course. I expected the students to learn the skills associated with these problems by trying to solve the problems, asking appropriate questions, and reviewing posted solutions. A few students followed this model. Essentially all of the students who did well on these problems heeded my council early in the semester to consult with me while trying to solve these problems. These students did learn how to tackle the problems and performed consistently throughout the term even on problems where they did not consult with me for that specific problem. This success could hopefully be expanded to include more students by incorporating the tutoring type instruction into the formal class time.

The problems can be difficult to write since it is important to keep the problems realistic yet solvable with limited quantitative skills. I want the students to have fun with these problems and for the most part this first attempt did not produce that effect, but I believe with more attention that can change in the next offering of the course.

In fact in the next offering of the course, I did incorporate the change of providing class time teaching the students how to solve these design problems. We spent time in class working on and discussing, in small groups and all together, the first two assigned design problems. At the time of this writing, two additional problems (not discussed in class) had been submitted: 90% of the students are submitting the problems and the average score is 8/10 points. On the first exam design problem in this term (to design a three note flute), 7 of 26 students earned 4/4 points and another 12 had only minor errors and received 3/4 points. These two indicators suggest that this small investment of class time on how to solve these problems has made a significant difference in student participation and performance.

Appendix: Test Stand Details for the Airfoil Experiment:

The test stand was built from plywood and pine boards (approximately $20). The blower is a salvaged furnace blower (obtained at no charge). The airfoils are mounted on two Accuride ® drawer slides (#2132 - approximately $10 for a pair). The drawer slides were mounted on machine screws passing through the short wind tunnel, which allowed a low friction pivot. The bearings in the slides also allowed low friction travel along the long axis of the slides (Figure 1). A machine screw passing through the extendable portion of the slide was connected to a load cell for measuring drag, one on each side. Two additional machine screws were used for mounting the airfoils, which were to be constructed to a width slightly less than the separation of the drawer slides. A third load cell was suspended from a pair of ring stands above the air foil (using the same attachment as the drag cells). The airfoils were mounted into the stand upside down to simplify the measurement of the lift. Spring scales could easily be substituted for the PASCO force sensors (load cells).

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