First-Year Hands-On Design on a Dime – Almost!

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Abstract

The implementation of in-class, hands-on activities in first-year engineering classrooms can easily become a costly endeavor. This is especially true when the number of freshman students in the incoming class exceeds 1200. Additionally, difficulties in delivery logistics such as class time management and student team formation can often make an instructor hesitant to attempt participatory exercises within the confines of a regular classroom and a fifty-minute class period. This paper presents our experiences in the design and execution of seven first-year hands-on activities that incur very minimal expense and that focus on several aspects of the engineering design process. Topics covered in these exercises include: reverse engineering; the concept of a decision matrix using consumer versus manufacturer viewpoints; design criteria versus design constraints; and engineering analysis (problem solving, application of scientific principles, and log-log graphing). While a major goal of these exercises is to involve the students in team-based active classroom learning, we have also developed out-of-class work/questions for the exercises that offer individual reflective components to compliment and strengthen the in-class learning experience. Along with a review of the exercises that highlights the learning objective and student response to each activity, the paper offers notes on delivery logistics that have been successful in our classrooms and an account of the expenses associated with each exercise. The worksheets that we have created for these activities are provided as an appendix to the paper for reader use, and solution keys to the worksheets are available from the authors upon request.

Introduction

In the past, experiential learning was often reserved for formal laboratory courses in which students were taught how to use testing equipment and how to record and analyze the measurements they made. Such courses usually required a special room (i.e., the laboratory) to house the equipment and to provide the space and safety features required for the experiments. Further, there was often an exposure disparity between material presented by formal lecture and the concepts presented through experiments performed in lengthy lab sessions. However, current engineering education practices often implement experiential learning in smaller doses to immediately compliment material presented in lecture and to offer an active mode of learning in courses for which no co-requisite lab is available. The value of immediate exposure is easily appreciated,[1] and dealing with actual objects has long been ranked first by merit among available teaching aids: "Wherever possible, show the student the actual object being discussed. Let him use as many of his senses as possible in getting acquainted with it. Actual contact … is better than thousands of descriptive words."[2] Implementation of active learning exercises, though, can be intimidating to the traditional lecturer and to the novice instructor due to administrative logistics in a traditional classroom setting and to meager allowable budgets for such undertakings. In this paper we offer our experience in working seven affordable active learning design exercises into the regular classroom for a large number (1200+) of first-year engineering students. These seven exercises are a sampling from our first-year hands-on effort that was piloted in fall 2000,[3] expanded to full implementation in fall 2001,[4] and continued through fall 2004. Assessment of the learning impact of our hands-on effort, as perceived by students and by faculty, is presented elsewhere.[4, 5] Here we offer a brief summary of each exercise that highlights learning objectives and anecdotal observations of student response, notes on successful delivery logistics, and an account of the expenses associated with each exercise. The worksheets provided in the Appendix are formatted for direct copy and use. In order to make the presentation of each exercise more understandable, we begin with some general information regarding our department, our first-year program for students entering the College of Engineering at Virginia Tech, and the basic logistics for our hands-on implementation.

General Information

The Department of Engineering Education (EngE), formerly the Division of Engineering Fundamentals, provides a home within the College of Engineering for all entering students bound for an engineering discipline or for Computer Science. These students are required to take a two-semester sequence of two EngE courses; the first course is common to all entering CoE students, and the second has two different tracks. Students bound for Computer Science, Computer Engineering, or Electrical Engineering take a digital version of the second EngE course. Students bound for the other engineering disciplines offered by the college (Aerospace, Biological Systems, Chemical, Civil, Engineering Science and Mechanics, Industrial and Systems, Materials Science and Engineering, Mechanical, Mining and Mineral, and Ocean) take a graphics/design version of the second EngE course. The common first course is an introduction to design and provides opportunities to explore the possible majors within the college. The seven exercises presented here are offered to students in the common first course.

Our incoming class has frequently exceeded 1200 students and, with the recent addition of Computer Science to the College of Engineering, we anticipate future classes to approach 1500 students. For first course administration to date, we have divided the large number of incoming students into sections of 32 students and provided enough instructors to cover the resultant number of sections (~40 sections with 3 or 4 sections per instructor). The instructors are usually full-time EngE faculty who also serve as academic advisors to the students in their sections. We are fortunate to have four classrooms that are dedicated for our use from one semester to the next (so we can envision hands-on implementation plans within these rooms). The classrooms are wide and shallow, and they are each currently furnished with three long tables that run nearly the width of the rooms, hence providing three rows per classroom. Seats are individual stackable chairs that can be moved as needed. With 32 students per section, and usually four students per team for the hands-on activities, we can accommodate all sections of the course by providing the four classrooms each with eight sets of the needed materials for a given exercise, as long as all materials are reusable from section to section. We also provide a set of classroom extras at the instructor's table for quick replacement of items that have worn out or disappeared. When consumables are involved in an exercise (e.g., Exercise # 1: Take Apart – Pull-back Car), we generally furnish each instructor with enough of the consumable item(s) for his/her sections. Dedicated classrooms are nice, but they are not necessary as long as the materials required for the hands-on exercises are easily transported to the classroom in use. During some semesters, we have needed classrooms other than our usual four, and we then provided dedicated wheeled carts that were stocked with hands-on sets and could be taken easily to the appropriate locations.

These basic logistics for the hands-on exercises will work for smaller classes, or for a larger number of students (>>1200) if that larger number of students can be divided to yield sections of 50 or fewer students. If such division into small sections is not possible, different hands-on implementation logistics would be in order. For example, if 200 students are to be served in one session, 50 sets of the hands-on materials would be needed, and it would be advisable to have a sufficient number of teaching assistants (TAs) present during class to yield a student/TA ratio of 30 or less. A maximum of ~30 has been reported to be the limiting workable student/TA ratio for administering active learning exercises in very large sections (200 to 300 students).[6] Classroom selection for such a session should take into consideration the classroom furnishings. Anchored seating could be workable as long as adequate table space is available and students can cluster quickly into teams. However, in large lecture halls with theater seating and very small pull-up desks, students will have difficulty just physically gathering into teams, and that translates to wasted class time.

Team assignments for these in-class activities can be accomplished in various ways. The critical issue here is to guard vigilantly against lost class time. If you have established teams for other, longer duration projects, you might consider using those established teams for the hands-on activities. This might afford you some time to observe how those established teams are truly functioning. Otherwise, with only the in-class portion of our activities being teamwork, team assignments can be made in the most convenient manner and several options come to mind (e.g., alphabetically, by seat location, by counting off, by color coding papers drawn out of a hat). However, if you choose to also allow the students to work in teams on the out-of-class questions, then you should give team assignment its proper consideration, as you would for any design project.

Another aspect of logistics to consider is how materials and worksheets are distributed to the students when the active exercise is to begin. If you have the means to distribute the worksheets electronically, it is best to ask the students to print their own hardcopy of the worksheet and bring it to class with them. This will save you the time and money associated with producing enough hardcopies for each student. It will also allow the students to review the worksheet before coming to class – an option that will aid reflective learners who may be somewhat uncomfortable with fast-paced in-class activities. A visual display of the worksheet projected during class is very useful for quickly answering questions that arise during the activity, but that should not be the only means for students to follow along. Teams will work more efficiently if each student has a hardcopy of the worksheet while doing the exercise. The best method for distributing the materials needed is first to assemble sets that contain all reusable items in appropriate containers (e.g., plastic zip bags) and sets of any needed consumables. Then position the sets at each workstation in the classroom before the students arrive. If that is not possible, which is usually the case for us, then place the sets in accessible locations in the class room and have a designated person on each team be responsible for retrieving them. If you are dealing with a very large number of students in a single class session, have TAs help with distribution. As a check, the first entry under IN-CLASS WORK on worksheets should be a list of the materials needed to accomplish the hands-on task.

The physical logistics of implementing active learning are one matter, and the buy-in of instructors is another. But, the buy-in hurdles to overcome have diminished with time as hands-on teaching becomes our norm. We have also always offered preview sessions for each activity wherein the instructing faculty are the practice set of students. We run the hands-on exercise in a prepared classroom and give the faculty an opportunity to experience the exercise from the students' perspective before implementing it. This has helped us improve logistics and has raised the comfort level of the faculty with the exercises. In our experience, we have also noted that implementing active learning exercises in the standard classroom does seem to lead to a louder class body, in general, and instructors should be made aware of this likelihood. We believe this side effect occurs because the students feel more comfortable with each other and with the instructor.

Assessment of our hands-on efforts is reported elsewhere,[4, 5] and the balance of this paper offers an overview of each exercise that includes anecdotal student response, costs, and notes from our implementation experiences. The worksheets for the exercises are presented in the Appendix.

The Seven Exercises

With the exception of Exercise # 3, which is linked to and should follow Exercise # 2, the exercises discussed below may be used independently and in any order. In our 15-week semester, there are 29 lessons in the common first EngE course. Thus the lesson number for typical use of an exercise in our course is an indication of when in the semester/course the activity might be successfully offered. Unless otherwise noted, the cost of each exercise is based on the preparation of 40 hands-on sets and service to 1200 students (who are divided among 40+ 32-student sections) using four dedicated classrooms. Please keep in mind that these activities are designed for first-year students whose skill levels and academic backgrounds span a broad range despite college admissions requirements and the passing of gateway benchmarks.

Exercise # 1: On reverse engineering, Take Apart – Pull-Back Car
Typically used during Lesson 1 of 29
Description: This exercise, offered during the very first lesson when used, serves as an icebreaker among the students and between the instructor and the students. It is meant to be both fun and thought provoking. The students are asked to compare the drive mechanisms used in the design of two types of toy cars. The small pull-back cars, which the students disassemble, use a spiral coil spring to store the potential energy generated during a backward pull. The spring is wound by a gear train put in motion by the reverse rotation of the back wheels of the vehicle. When the car is let go, the potential energy stored in the spring is converted to the kinetic energy of the vehicle as it moves forward, driven by the unwinding of the coil spring, which produces forward rotation of the back wheels through the gear train. Pull-back cars may be known to some of your students as "penny racers." The second, larger toy car is often called a friction car, and uses a flywheel to store kinetic energy, which keeps the vehicle moving in the same direction as the motion that induced rotation of the fly wheel. For the flywheel vehicles, prior removal of the body casing reveals the flywheel and the gear train, and no further disassembly is needed. If a visible mark is placed on the flywheel's perimeter and on one of the vehicle wheels (these vehicles usually have both front- and back-wheel drive), students can count the number of flywheel rotations produced by a single rotation of the vehicle wheels. In other words, they can determine the gear-up ratio of the gear train. Student response to this activity was very positive. Many had never taken a pull-back car apart to understand its operation though most had played with them in childhood. Many students had never heard of a flywheel or observed a drive mechanism that employed one. The OUT OF CLASS questions on the material properties involved in the toy car mechanisms (elasticity and inertia) provoked long discussions in the resident halls. The use of toys for this exercise was a deliberate move on our part because toys are not intimidating and their operation is usually very easy to understand. Use of a complicated, or otherwise intimidating, item would not serve to break the ice and warm the classroom; and it is the cool engineering classroom environment that hampers first-year retention[7] that we are trying to mitigate.

Special Logistics Notes:
1. This exercise is comfortably done in twenty minutes. If able, the instructor can wander among the teams in the classroom while students are engaged with the toy cars. The informal conversations that develop on such occasions make the instructor very approachable.
2. Re-assembly of the pull-back cars is not recommended. The gear train is composed of many tiny nylon gears that spill out of place when the gear compartment is opened. So, we consider the pull-back cars to be a consumable.
3. To save classroom time, the flywheel cars can be provided to the students with the body casing already removed and the flywheel and vehicle wheel already marked.
4. Plastic dinner plates in a dark color work well for take-apart trays and are reusable.
5. Safety glasses would be a good addition to this exercise.

Materials needed and associated costs for a first run:

300 pull-back cars @ $0.60 each (wholesale) → $180.00

40 small screwdriver sets @ $1.00 each → $40.00
40 flywheel cars @ $1.00 each → $40.00
40 plastic dinner plates →$3.00
40 plastic zip bags gallon size → $5.00
40 plastic zip bags snack size → $3.00
Total first run cost → $271.00

Materials cost of subsequent runs:
300 pull-back cars → $180.00

Exercise # 2: On design decision matrix, Hands-On – Design Comparison I
Typically used during Lesson 1 of 29
Description: This activity is used more frequently for the very first lesson (as an alternate to the pull-back car take apart). The students are provided with three types of staple removers and, of course, with some staples to remove. The three removers are labeled A, B, and C to facilitate discussion, and they vary a good deal in design and operation. Through actual use of the removers to take out both standard and mini staples that are stapled through several sheets of paper, the students evaluate staple remover design from a consumer standpoint. In doing so, they are guided through the basic procedure used to construct a design decision matrix. In the OUT OF CLASS questions, students are asked to examine their in-class work to numerically justify their choice of staple remover and also to consider staple remover design from a manufacturing viewpoint. Student response to this exercise is positive. The activity functions as a good icebreaker, and every student on the team is doing something during the exercise. Many had previously used two of the staple removers (types A and C), but most (125 students out of 128 in four sections) had never seen the B type. Because this is usually a Lesson 1 activity, we wanted to avoid anything overly complicated or mechanical in design, so students would not be intimidated by the exercise.

Special Logistics Notes:
1. Time required for this activity is twenty minutes.
2. This exercise takes a bit of preparation work to produce the stapled sheets. If students are asked to staple their own sheets and then remove the staples, the exercise takes more class time, the stapled condition is less uniform across the classroom, and students lose focus on remover design with the extra task of stapling. Stapled sheets are considered a consumable.
3. Heavy-duty staples were also used in the first run of this exercise, but they were very hard on type B and type C removers, and we needed to replace many of those removers from our stash of extras.

Materials needed and associated costs for a first run:
40 Type A staple removers @ $0.80 each → $32.00
40 Type B staple removers @ $1.30 each → $52.00
40 Type C staple removers @ $1.00 → $40.00
40 plastic cups 16 ounce size → $3.00
Staples, standard and mini → $10.00

Total first run cost → $137.00

Materials cost of subsequent runs:

Staples, standard and mini → $10.00
Replacement staple removers → 25.00
Total subsequent run cost → $35.00

Exercise # 3: On design criteria, Hands-On – Design Comparison II

Typically used during Lesson 2 or 3 of 29

Description: This exercise is a follow up to the design comparison of Exercise # 2. Here the students compare at least four different designs of items meant for the same purpose. We use items that are meant for a familiar purpose, so the students are not wondering *what* they are looking at, but rather noticing differences among the designs. If the items are for a familiar purpose, it is also likely that the students will be able to form opinions more easily on the design of the items and be more forthcoming with their opinions. This facilitates group discussion. In the course of examining the four designs, the students are asked to generate a decision matrix from a manufacturing viewpoint (on a transparency sheet) and present it to the class. Within the discussion that ensues, the instructor has the opportunity to make clear distinction between design criteria (used in a decision matrix) and design constraints with a wealth of first-hand examples. Students like this exercise. They appreciate the familiarity of the objects and yet are intrigued by how different the designs for an everyday item can be. Four to six is a good number of different designs for a given purpose. More will not allow the students sufficient time to examine each item, create a decision matrix, and present to the class.

Special Logistics Notes:

1. This exercise may easily occupy a full class period, but it can be done in 30 minutes.
2. Team size for this exercise is larger (eight to ten persons) to make the number of teams fewer, so that presentation and discussion do not run over to the next class meeting and, hence, lose momentum.

Materials needed and associated costs for a first run:

24 12-inch rulers, six each of four designs → $30.00
24 bottle openers, six each of four designs → $40.00
24 toothbrushes, six each of four designs → $40.00
300 single sheets of transparancy film →$70.00
20 fine line permanent markers → $15.00
Total first run cost → $195.00

Materials cost of subsequent runs:

300 single sheets of transparancy film →$70.00

Exercise # 4: On reverse engineering, Toaster Design and Reverse Engineering
Typically used during Lesson 15 of 29
Description: In this exercise, students partially disassemble a very familiar electromechanical devise, a toaster. In the toaster design we chose to use, control is based on temperature via the response of a bimetallic strip designed to change shape (curve) as the strip is heated. Certainly, this is not the best of toaster designs, but toasters so made are relatively inexpensive and do offer a wealth of opportunity in terms of design discussion. The understanding of bimetallic strip design for use in toaster control mechanisms is also complimentary to a graphing problem we use on shape memory alloys. Students really enjoy this activity. When done in pairs, each student gets a good dose of understanding the operation and design of a toaster. We have also offered this exercise using two different brands of toasters with interesting variations on the handle release mechanism and the job of the bimetallic strip in that mechanism.

Special Logistics Notes (two students per team, 20 sets):
1. This exercise will require a full 50-minute class period.
2. To minimize costs, this exercise is rotated through the four classrooms as opposed to running concurrently in all four rooms. The rotation takes a bit of syllabus juggling, but it is doable. With rotation through the rooms and a reduction in team size to two persons per team, 20 hands-on sets are used for this exercise. Costs listed below reflect this change in logistics.
3. Success of this exercise is dependent on the instructor's familiarity with the toaster design.

Materials needed and associated costs for a first run:
20 bimetallic strip toasters @ \$8.00 each → \$160.00
20 Philips screwdrivers @ \$1.00 each → \$20.00
40 safety glasses @ \$2.00 each → \$80.00
20 paper food boats →\$2.00
Total first run cost → \$262.00

Materials cost of subsequent runs:
2 replacement toasters @ \$8.00 each → \$16.00

Exercise # 5: On engineering analysis problem solving, Hands-On – Surface Area
Typically used during Lesson 3 or 4 of 29
Description: This exercise is one of the least expensive activities that we have implemented. Student teams are given a length of hexagonal swimming pool noodle and asked to determine the surface area of their section of the noodle. Each team in the classroom is given a different length of noodle (from 1 to 8 inches, increasing in one-inch increments), so each team will have a different answer for the surface area. Of course, the surface area is a linear function of the length of the noodle because the cross section has a constant shape along the length. We point this linear relationship out as the surface area answers for each length are gathered from the teams. We then revisit that linear relationship when course topics move to graphing and empirical functions. The noodles used in this exercise also have a through-hole that runs along the length axis of the noodle. Students find this to be a challenging exercise. It requires direct application

of their trig and geometry skills. Invariably, half the class will believe that the through-hole can be neglected in the calculation of the surface area. And, there are always a few students who have never considered that the concept of area could apply to a three dimensional shape. The second portion of the activity is to imagine the noodle piece cut in half to produce two identical halves and then determine the area of one of the halves. The halving procedure imagined uses a cutting plane that is parallel to the noodle length, or a cutting plane that contains a point-to-point or an edge-to-edge body diagonal.

Special Logistics Notes:
1. This exercise can be accomplished easily in 15 minutes.
2. To help the students visualize the imagined halving process, the instructor is provided with noodle pieces that have actually been cut in half the various ways to produce two identical halves. The instructor chooses which manner to halve the noodle pieces and can visit each team to show the students.

Materials needed and associated costs for a first run:

6 5-ft hexagonal cross-section swimming pool noodles @ $1.50 each → $9.00
40 12-inch rulers @ $0.25 each → $10.00
Total first run cost → $19.00

Materials cost of subsequent runs: → $0

<u>Exercise # 6: On engineering analysis application of scientific principles, Hands-On – Archimedes' Principle</u>
Typically used during Lesson 25 of 29
Description: The student teams are given a rectangular wooden block with graduations scored on one face. The blocks are varnished to seal them. Students measure the block dimensions and then place their block in water to determine the weight of the block using Archimedes' principle. They must measure the volume of water displaced by noting the water level on the block using the graduations. This is a fairly straightforward activity, but it offers the instructor an opportunity to discuss mass, weight, and the application of Newton's Second Law of Motion, as well as Archimedes' principle. Students find some of the OUT OF CLASS Questions very difficult to answer, particularly # 4 and # 5. From the instructor's viewpoint, it is quite interesting to read student responses to those questions.

Special Logistics Notes: N/A

Materials needed and associated costs for a first run:

40 scored and sealed wooden blocks @ $20.00 each → $800.00
40 12-inch rulers @ $0.25 each → $10.00
4 1 gallon tubs for water → $3.00
Total first run cost → $813.00

Materials cost of subsequent runs: → $0

Exercise # 7: On engineering analysis log-log graphing, log-log Plotting Worksheet
Typically used during Lessons 9 and 10 of 29
Description: This exercise incurs no cost if students are required to print their own hardcopy of the worksheet. Students are given a three cycle fully logarithmic grid and asked to plot four points on that grid. The first difficulty they have is in calibrating the axes. The point coordinates selected for this exercise should be challenging and should span a negative power of ten on at least one axis. Using a transparency of the worksheet with the points plotted in red, an instructor can quickly move from student to student and check the positions of the plotted points. The second part of the exercise is done in the next lesson. It requires the students to determine the equation of the line on the grid using the method of selected points. Students are usually very appreciative to have the opportunity to work on these exercises during class and to get immediate feed back on how they are doing things. For fall semesters with over 1000 students being tested, the average points earned on exam log-log graphing questions jumped from near 50% of the graphing points to an average earning of about 90 % through implementation of this exercise.

Special Logistics Notes:
1. The point-plotting portion of this exercise takes about 15 minutes and is done individually by each student, though neighbor consultation is encouraged.
2. The equation determination, also done individually, takes about 15 minutes and is best done in the subsequent lesson.
3. We divided this exercise between two lessons so the students could plot on a log-log grid and be checked in class, and then attempt homework on their own. In the next class period, they have a strong interest in how well they did on their own, and they ask eagerly for clarifications in the second portion of the exercise.

Materials needed and associated costs for a first run:
Worksheet only → $0
Total first run cost → $0

Materials cost of subsequent runs: → $0

Summary and Conclusions

A summary of the exercise costs on a per student basis is presented in Table 1. The values listed are calculated by dividing the cost of the exercise (obtained from the itemizations above) by the number of students served, which is provided in parentheses in the column header. These costs can be reduced slightly as some items used for one exercise may be used in others (e.g., the 12-inch rulers in #3, #5, and #6). We have calculated the costs for one, two, and three fall runs for each exercise. From those entries, we have determined the total cost per student to run all seven exercises and the average cost per student per exercise. With just one run, this average cost is $0.20, which we consider a very minimum investment per student. For two or three runs, the average cost per student per exercise to implement these exercises drops to $0.12 and $0.09, respectively, a dime – almost!

Table 1. A summary of exercise costs on a per student basis.

Exercise	First Run Cost per Student (1200)	Two Runs Cost per Student (2400)	Three Runs Cost per Student (3600)
# 1 Pull-Back Cars	$0.23	$0.19	$0.18
# 2 Staple Removers	$0.11	$0.07	$0.06
# 3 Designs Comparison	$0.16	$0.11	$0.09
# 4 Toaster Take-Apart	$0.22	$0.12	$0.08
# 5 Pool Noodle Surface Area	$0.02	$0.01	$0.01
# 6 Archimedes' Principle	$0.68	$0.34	$0.23
# 7 log-log Plotting	$0.00	$0.00	$0.00
Total for all 7 Exercises	$1.41	$0.79	$0.64
Average per Exercise	$0.20	$0.12	$0.09

Bibliography

1. Piaget, J. *To Understand is to Invent: The Future of Education*. Grossman Publishers. 1973. p 15.
2. ASEE Booklet: *You and Your Students*. Prepared by MIT Faculty Committee, Prof. Robley D. Evans, Chair. ASEE. 1968. p 25.
3. Goff, Richard M. and Jeffrey B. Connor. Hands-On Experiences in the First Year Engineering Classroom. *Proceedings of the 2001 ASEE Annual Conference and Exposition*.
4. Connor, Jeffrey B. and J.C. Malzahn Kampe. First Year Engineering at a Virginia Polytechnic Institute and State University: A Changing Approach. *Proceedings of the 2002 ASEE Annual Conference and Exposition*.
5. Connor, Jeffrey B. and Richard M. Goff. Assessment of Providing In-Class, Hands-On Activities to Virginia Tech's First Year Engineering Students. *Proceedings of the 2001 ASEE Annual Conference and Exposition*.
6. Imbrie, P.K. *Active Learning Workshop*. NSF Sponsored Sugar Lake Conference, Grand Rapids, MN, July 2002.
7. Daempfle, Peter A. An Analysis of the High Attrition Rates among First Year College Science, Math, and Engineering Majors. *Journal of College Student Retention: Research, Theory and Practice* 5 (1) 2003-2004. pp 37-52. As referenced by Marrero, Tom, and Andrew Beckett. Freshman Interest Groups: Creating Seamless Learning Communities to Enhance Student Success. *Proceedings of the 2005 ASEE Annual Conference and Exposition*.

Biographic Data

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Appendix: Worksheets for the seven exercises

Exercise # 1: On reverse engineering

Take Apart – Pull-Back Car

IN CLASS WORK: In teams of four persons
Please follow these directions, letting each member of the team participate, and briefly answer any questions in the spaces provided.

1. Things your group should have: a) a small pull-back car; b) a larger vehicle; c) a plastic plate (for a take-apart tray); d) a set of four small screw drivers; and e) two zipper plastic bags.

2. Before you take it apart, look at your pull-back car. What features or abilities does it have?

3. Remove the small Phillips screw and take off the outer car shell. Look at the features again, observing the motion of the visible gears.

4. Pull down on the front end, lift out the white gear compartment, and (on the plastic plate) pry the gear compartment open with a flat-blade screwdriver. Most of the gears will spill out of the casing, but the largest should remain in place. Rotate that gear to see what happens. Now remove that gear to see what its rotation does.

5. Now look at the larger vehicle. DO NOT take the larger vehicle apart! What does it do?

6. One way to measure the overall "gear-up" ratio in a mechanism like the one you see in the larger vehicle is to count the number of flywheel rotations produced by one rotation of the vehicle wheels. Find the markings on your vehicle and do that.

Gear-up ratio = (number of flywheel rotations) / (number of wheel rotations) = ________

7. Return all the pullback car pieces to your instructor in the small zippered plastic bag. Put everything else in the other, larger plastic bag, and return it to the classroom box.

OUT OF CLASS QUESTIONS: Independent/Individual work

1. Briefly, what is the mechanism that makes the pull-back car move forward after being pulled backward?
2. What property of matter is used in the design of the pull-back mechanism?
3. What is the mechanism that keeps the larger vehicle moving after you let go of it?
4. What property of matter is used in the design of the larger vehicle's mechanism?
5. Which mechanism is the more efficient design in terms of your input energy?

Exercise # 2: On design decision matrix

Hands-On – Design Comparison I

IN CLASS WORK: In teams of four persons
Please follow these directions, letting each member of the team participate, and provide the information requested in the spaces provided.

1. Things your group should have:
   a) three different types of staple removers labeled A, B and C;
   b) two types of staples, labeled "mini" and "standard," stapled through several sheets of paper; and
   c) a plastic cup to collect removed staples

2. Before taking any staples out, look at the design of each remover. Make a very simple sketch of each remover type just to use as a memory aid.

A (price: $ 0.79) B (price: $ 1.29) C (price: $ 0.99)

3. Now it's time for some assessment, so you will need to remove staples. Each team member should remove **two** mini and **two** standard staples with Remover A, filling in the table below as the staples are removed. Then do the same with Remover B and Remover C.
To fill in the table, please rate the staple removers with regard to the category at the top of the column using this scale:

1 = poor 2 = below average 3 = average 4 = good 5 = excellent

	Appearance	Cost	Comfortable to hold/use	Removal of mini staples	Removal of standard staples	Durability
A						
B						
C						

4. Think about what you rated above, and give each category a point value by dividing 100 points among the six categories according to how important **you** consider each category in staple remover design.

Appearance	Cost	Comfortable to hold/use	Removal of mini staples	Removal of standard staples	Durability
____ points	____ points	____ points	____ points	____ points	____ points

5. If you could purchase only one of the three staple removers, which would you buy? Why?

6. Please dispose of removed staples in the trash can at the front of the room, then place the staple removers back in the cup and return these to the side table. Thank you!

OUT OF CLASS QUESTIONS: Independent/Individual work

1. Engineers often speak in terms of numbers. How can you use the information you gathered in class to justify numerically which staple remover you would purchase?

2. If you were in the business of making staple removers to sell, would you distribute the 100 points among the six categories in the same way you did for In-Class Item 4 above? Why or why not?

3. From the manufacturing viewpoint, list at least three other categories that you consider relevant to staple remover design.

Exercise # 3: On design criteria (as compared to design constraints)

Hands-On – Design Comparison II

IN CLASS WORK: In teams of four to ten persons

The class should divide into three groups by rows. Group 1 (Row 1) should gather at the right end of their row, Group 2 (Row 2) at the left end of their row, and Group 3 (Row 3) at the right end of their row. Your instructor will provide your group with a set of objects; each object in the set is designed to accomplish the same task. Please follow these directions, letting each member of the group participate, and provide the information requested. Please be sure that all of the objects in your set and the permanent marker are returned to the instructor for use in the next section.

1. Things your group should have:
    a) many members to generate many ideas; make one list of names of those in your group
    b) a transparency sheet and a fine point permanent marker; and
    c) a set of at least four objects meant for the same task; write the object type on your list of names for the group
    Possible Object Types: 12-inch rulers, bottle openers, or toothbrushes

2. On the transparency sheet, create a decision matrix for the manufacture of your object type using the objects in your set as the candidate designs. Reflect on the class discussion about the staple removers to assist you, and remember that this decision matrix is to be made from the manufacturing point of view. Using your decision matrix, present and justify your design choice to the class.

3. Place the set of objects and the permanent marker back in the plastic bag and return this bag to your instructor. Turn in the list of names for your group and the transparency that has your group's decision matrix to your instructor.

Exercise # 4: On reverse engineering

Toaster Design and Reverse Engineering

Note: The toaster MUST BE completely and properly reassembled prior to leaving class.

IN CLASS WORK: In teams of two persons

Follow these steps in order, and use green engineering paper to answer any questions or address any deliverables requested.

Your station should have: two pairs of safety glasses, one toaster, one Philips screwdriver, and a paper boat to collect parts.

1. Put on safety glasses. Do Steps 2 and 3 before you take anything apart.
2. Look at the sides of the toaster, and note that there is a handle you must push down to turn on the toaster and there is also a slide control to select the darkness setting for your toast.
3. Look at the top of the toaster, and note that you are directed to use a specific slot if you intend to toast only one slice of bread. Look into both slots. Do you see anything different between the two slots? Describe any differences, being sure to indicate which is the slot for toasting only one slice of bread.
4. Carefully pull off the knobs of the handle and slide control. Remove the screws or the bolts, nuts, and washers holding the plastic ends and sheet metal cover of the toaster. Please be careful! Put the knobs and screws/bolts, nuts, washers in the paper boat, and lift off the plastic ends and the sheet metal cover. **STOP –** do not disassemble any further.
5. Why does the toaster turn on when the handle is pushed down?
6. Why does the toaster turn off when the handle pops back up?
7. What holds the handle down during the toasting process?
8. What must happen to release the handle so the toaster shuts off?
9. Why does the bread get toasted when the toaster is on?
10. The heating elements in the toaster are nichrome ribbons that have high electrical resistance, which turns much of the electrical energy in the current to heat. These ribbons are oxidation-resistant through the temperature range experienced in a toaster. The nichrome ribbons are wrapped on mica boards. Look at the way the ribbon is wrapped on the boards of your toaster. Look at the way the ribbon is wrapped on the "other" toaster model that some of your classmates are using. Do you see any differences?
11. Now, inside one of the bread slots is a vertical metal strip that you should watch as you move the slide control for the darkness setting.
12. What happens to the metal strip when the slide control moves from the lightest setting to the darkest setting? Look at and describe the effect of the slide control motion on anything that interacts with the metal strip. You may need to hold the toaster handle halfway down to observe all that you should.
13. We know that the slide control has a strong influence in how long the toaster handle stays down to keep the toaster heating elements on. But we need to understand how the metal strip in the slot is involved. If you have a toaster with a solenoid (look for a coil of copper wire) on one side near the bottom, the vertical metal strip itself is a *bimetallic* strip. If your toaster

does not have a solenoid, then there is a horizontal *bimetallic* strip (attached to the vertical metal strip about an inch from the top of the toaster) that extends out of the toaster through a cutout in the galvanized sheet. The bimetallic strips used in toasters are composed of two metals that are rolled together and that expand very differently when they are heated. One metal expands a great deal and the other expands very little. Now, because the two metals are physically bound together, when such a bimetallic strip is heated it will bend or curve in response to the stresses that are generated in the strip by the different thermal expansion characteristics of the two metals. See Figure 1, for which the white metal expands more than the gray. A good way to remember this is to understand that the metal that has expanded more will always be on the outside of the curve to accommodate its larger size by virtue of a larger radius of curvature. Of course, not all types of bimetallic strips are designed to function with heat as those that are used in toaster control mechanisms.

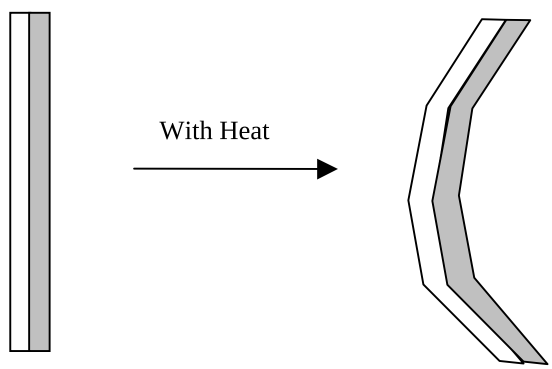

Figure 1. Bimetallic strip used in toaster control mechanism

14. Explain how heating the bimetallic strip in your toaster affects the toaster operation.
15. Reassemble your toaster, making sure that the "One Slice" indicator is pointing to the proper slot.

OUT OF CLASS QUESTIONS: Independent/Individual work

16. Explain why there is a specific slot for toasting only one slice of bread.
17. In terms of your toaster's operation, explain this scenario. CD Jones is home on break, and a younger sibling has toasted their bread first. CD's bread goes into the toaster (one exactly like yours) immediately after the sibling's bread pops up. CD's toasted bread does not come out of the toaster looking the same as the sibling's. Assume the bread slices used in both cases are identical in every way and that two slices are toasted in each case.
18. Would you say the toaster is time controlled or temperature controlled?
19. Using your toaster as a guide, what design criteria would you use to evaluate toaster design and how would you weight the criteria (splitting 100 points among them).

Exercise # 5: On engineering analysis – problem solving

Hands-On – Surface Area

Objective: Determine the surface area of the given object, and then determine the surface area of one half of that object if the object were split as shown by your instructor.
DO NOT CUT YOUR OBJECT.

IN CLASS WORK: In teams of four persons

1. Things your group should have
   a) a 12-inch ruler (use inches for your measurement units)
   b) a section of a hexagonal swimming pool noodle (this is your object).

2. Make a sketch of your object and, on the sketch, identify the measurements you will need to determine the surface area of your object. Assume the cross-section of the object is a regular polygon.

3. Make and record all the necessary measurements that you will need to later determine the surface area of your object out of class. Use inches.

4. New Object: **Imagine** that the object you have is cut in half the way your instructor has shown you. Make a sketch to serve as a memory aid. What would the surface area of half of your object be? (Answer for "Out of Class Questions.")
   DO NOT CUT YOUR OBJECT.

OUT OF CLASS QUESTIONS: Independent/Individual work

1. Draw two freehand pictorial sketches of your noodle object. Make one sketch an isometric pictorial and the other an oblique pictorial. Use the hexagonal end as the front face of the object.

2. Determine and report the surface area of your object. Show all your work.

3. Determine and report the surface area of the imagined half-object produced if your noodle section were split the way your instructor indicated. Show all your work.

Exercise #6: On engineering analysis – application of scientific principles

Hands-On Archimedes' Principle

Objective: Determine the weight of an object through the application of Archimedes'principle.

Background:
According to Archimedes' principle, the buoyant force on an object wholly or partially immersed in a fluid at rest is equal to the weight of the fluid displaced.

IN CLASS WORK: In teams of four persons

1. Things your group should have:
    a) a 12-inch ruler
    b) a wooden block with graduations scored on one face
    c) a container of water
2. Make the single view sketches to identify and record the measurements you will need to later determine the weight of the wooden block using Archimedes' principle. Make an isometric sketch showing the scored graduations on the front face of the block.
3. Make and record all necessary measurements.

OUT OF CLASS QUESTIONS: Independent /Individual work

1. Determine the weight of the block in lb_f.
2. What is the vertical force exerted on the block by the water?
3. The block is floating in the Atlantic Ocean. Does the block float higher, lower, or at the same level than in the classroom? Why?
4. A rowboat, in a very small pond, is carrying a large cannonball. The cannonball is dropped over the side and sinks. Does the pond's water level rise, fall, or stay the same? Why?
5. Estimate the specific gravity of the human body.

Exercise # 7: On engineering analysis – log-log graphing

log-log Plotting Worksheet Name _________________________

IN CLASS WORK: Independent /Individual work
Lesson 9: Plot the four given points on the log-log grid below, and label them A, B, C, and D as appropriate. These points will not produce a straight line. For now, disregard the line drawn on the grid; we will use it in Lesson 10.

A (180, 0.75) B (63, 11.5) C (3300, 31.0) D (2550, 3.70)

IN CLASS WORK: Independent /Individual work
Lesson 10: Using the line on the log-log Plotting Worksheet, determine the equation of the line if the line represents "pressure as a function of temperature" with pressure measured in atmospheres and temperature in Kelvin's. Use the method of selected points and the indicated coordinates of Point 1 and Point 2 to determine the equation constants.