AC 2008-809: HANDS-ON PROJECTS IN AN EARLY DESIGN COURSE

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Hands-on Projects in an Early Design Course

Abstract

This paper presents an overview of both team and individual projects over a five-year period from 2002 to 2006 in an early mechanical engineering design course. All ten, semester-long team projects are hands-on and require the design, fabrication and testing of an artifact. Of the six individual projects described: two are experimental; one requires reverse engineering; one is hands-on; and two are related to design evaluation and the design process. Example results are given for two of the team projects and two of the individual projects. Student surveys indicate that engineering students enjoy working on these projects and learn from the experience.

Introduction

Early, hands-on, design experiences in the BSME curriculum have become more common recently even though providing "hands-on" experiences in an engineering program is not new[1,2]. Prince and Felder[3] reviewed over a hundred studies addressing the assessment of various teaching strategies and concluded that "inquiry learning" and "problem-based learning" were generally more effective than others. The engineering education literature provides many examples of this type of learning through "hands-on" or "learning-by-doing" projects. In fact many schools have introduced innovative "hands-on" activities and hardware into their freshman courses[4-11], their sophomore courses in mechanics[12-20] and thermodynamics[21-27] as well as in other engineering courses[28-35], "non-majors" courses[36, 37] and high school courses[38-40].

We introduced a sophomore design course, including a semester-long, team design, build and test project, in 1980 and have offered the course each fall and spring semester ever since to between 30 and 75 students. The author was an observer of the course for the first eleven years and has been the only instructor of the course since 1991. The course content has changed over the years, but has been fixed for the past ten years. While the semester-long, team project changes each semester, its format has more or less reached a steady state. Individual design projects are also assigned in the course.

Overview of Project Philosophy, Format and Requirements

This paper will focus on descriptions of the team design projects and some individual projects assigned in our sophomore design class from 2002 through 2006. Sample results for two of the team projects and for two of the individual projects will also be given. The common thread through all the team design projects is the attempt to recognize several aspects of the design process and not simply to focus on the testing results or the "competition." The expected outcomes from the team design projects are:

- Students should be able to apply the early steps in the design process beginning with identifying the problem, preparing complete specifications, gathering information, ideating, recognizing suitable concepts, selecting the best alternatives, synthesizing prototypes, and testing;
- Students should demonstrate that they can overcome the practical difficulties in taking a design from the conceptual stage to the final working device;
- Students should be able to work effectively in teams to produce a satisfactory product, to recognize the issues that potentially could disrupt the team, including personality related dysfunctions, and know when and where to seek help if things are not working out; and
- Students should demonstrate that they can prepare technical documents such as progress reports, final reports, extended abstracts, etc.

In the beginning any design project seemed to be simply a "good" idea for a design class. Over the years, however, experience has taught us that there are useful "guidelines" for developing and administering the projects. These guidelines are summarized below:

- Use no external sources of energy, i.e., all energy sources, e.g., batteries, are part of the device.
- Prefer gravity as the source of energy.
- Attempt to develop project requirements that could potentially be satisfied with multiple successful design concepts; force teams to justify the selection of their concepts.
- Include constraints on the device itself, e.g. size, weight, deployability, etc.
- Include both minimum expectations for performance (pass/fail) and a quantifiable goal, e.g., maximum a figure of merit.
- Have students compete against the yard stick or the clock but not against each other directly.
- Limit human interaction with the device, preferably eliminating it completely during the testing phase.
- Have deliverables submitted regularly throughout the time period of the project. (Spread the pain.)
- Have one or more "tests of concept" scheduled (so the team experiences the difficulty in taking a concept from the drawing board to the prototype before the final testing).
- Plan several meetings with each team and force all team members to participate in the discussion; assign a team deliverable for each meeting, e.g., Gantt chart, task assignments, test results, the current prototype, etc.

More information[41] is available on the development of these outcomes and guidelines.

The testing part of the team project currently has two parts: An Initial Testing of the device subject to a reduced set of constraints and requirements at the mid-point of the project and a Final Testing in which performance is quantified by establishing a well-defined figure of merit based on performance goals and problem constraints. The artifact itself is evaluated using a rubric that requires an evaluation of robustness and reliability, esthetics, and crowd-pleasing characteristics, as well as, the creativity of the team in both selecting and executing the concept.

An overview of the format for the team project is now given. The project description is given to the class the first week of the semester. (See the example for Fall 2005 in the Appendix.) Each student has three weeks to write a formal proposal describing and evaluating at least two distinct concepts for a solution to one or more of the required functions of the project, e.g., concepts to satisfy the Initial Testing requirements. (Instruction in technical communications is provided with "just-in-time" workshops given by the University Writing Center during the course "studio" time.) Normally, a draft is submitted, graded, and returned for resubmission. The draft and the resubmission usually count equally, together representing about 10% of the individual course grade. Students self-select into teams of four (to the extent possible) in the fourth week. Typically ten to fifteen teams are formed. The major deliverables for the project are usually: progress reports, a final report, a presentation, a successful initial testing, a successful final testing, and a functioning artifact for evaluation. The Initial Testing with a reduced set of requirements occurs in the seventh week. This testing is on a pass/fail basis, and teams that are unsuccessful must meet individually with the instructor to demonstrate a successful device (for reduced credit) within the next week. Failure to produce a successful Initial Testing disqualifies the team for the Final Testing (and about 25% of the project grade). The Final Testing is performed in a public venue (usually the lobby of the Engineering Building) during the tenth week. There is both a minimum performance requirement and a goal to maximize a figure of merit. The grade for Final Testing is based solely on the figure of merit. (Functionality is a necessary requirement of all engineering design.) Teams present their devices for a design evaluation immediately after the Final Testing (or sometimes after the team presentation). The instructor evaluates the devices according to an advertised rubric based on the specifications and requirements given[41] (for about 20% of the project grade). A final presentation and a Final Report are due during the twelfth week. A poster (to be displayed with the capstone course posters) or extended abstract may also be required. About 50% of the project grade is based on the communication elements. During the semester the teams meet with the instructor at least three times to discuss their progress and difficulties, including personal issues. Autorating[42] peer evaluations are conducted, and a poor rating by teammates, confirmed by the instructor's observation or other input, will result in the grade reduction for the individual.

Examples of Team Design Project Problem Statements

As noted above an example of a team design project description, as distributed to the students, is given in the Appendix. Ten summarized team problem statements are now given, but most of the details, e.g., statements on the schedule, the reporting requirements, evaluation, preference for gravity, etc., have been omitted.

Problem Statement (spring 2002)

Each team will design and fabricate a structure and all the auxiliary systems (hereafter called the "device") to move an object a minimum horizontal distance and a minimum vertical distance, and then return it to near its initial position, in a specified time increment in a limited space and without operator intervention. The device will operate on top of a table provided by the instructor. The "object" (to be selected by the team) must be visible from a distance of at least 30 feet and remain visible to the audience throughout the run. The requirement for the Initial Testing is to move the object from rest and in contact with the top surface of the table to a point at least 36 inches (horizontally) away and in contact with the top of the table in a time period between ten and fifteen seconds. During the movement the object must travel through a point at least 12 inches above the table. The device must weigh less than five pounds. The requirements for the Final Testing are to move an object (the larger and heavier as compared to the device the better) from the table top a minimum of 36 inches horizontal and 18 inches vertically, and after a minimum five-second delay, i.e., object remains essentially motionless for five seconds, to return it to near its initial position, in the total time of between 15 and 25 seconds with 20 seconds the preferred time. In its final resting place the object's contact area with the table must partially overlap its initial contact area with the table. The device must weigh less than ten pounds (lighter devices preferred), and be initially deployed from a six-sided container of volume less than 8.00 cubic feet (smaller containers preferred). Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = 2\,(5 - |20 - \sigma|) + (8 - \delta) + (10 - \mu) + 10\,\phi + 10\,\theta$$

where

- σ is the total run time in seconds;
- δ is the volume (in cubic feet) of the container (actually the cube of its longest edge dimension); if the volume is less than 1.00 cubic foot, set δ=1;
- μ is the mass of the device in pounds; if the mass is less than one pound, set μ=1;
- ϕ is the weight of the object divided by the weight of the device; if the ratio is greater than 1, set $\phi = 1$; and
- θ is the longest dimension of the object divided by the longest edge dimension of the device; if the ratio is greater than 1, set $\theta = 1$.

<u>Problem Statement (fall 2002)</u>

Each team shall design and fabricate a structure and all the auxiliary systems (hereafter called the "device") to transport up to ten ping pong balls to a height of at least twelve inches before depositing them sequentially (in one second of longer intervals) into a provided container, in a specified time increment in a limited space and without operator intervention. The device will operate on top of a table provided by the instructor. The operator will initiate, but not contribute to, the movement of the balls, and shall have no further contact with the device, the table or the balls. Both the device and the balls shall remain at all times within the space above the plane of the top of the table and not higher than 24 inches above the table. The requirement for the Initial Testing is to move two ping pong balls, sequentially from rest and in contact with the top surface of the table to a point at least 12 inches above the table and then to deposit them into the provided container (at least one second apart) in less than 10 seconds. The device must weigh less than three pounds. The requirement for a successful Final Testing is to transport at least five ping pong balls from the table top a minimum of twelve inches vertically and to deposit them in a provided container, sequentially (at least one second apart) in less than thirty seconds, the shorter the time the better. The goal for the Final Testing is to transport ten ping pong balls sequentially into the container as described above. The device must weigh less than five pounds (lighter devices preferred), and be initially deployed from a six-sided container of volume less than 4.00 cubic feet (smaller containers preferred). Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = (30 - \sigma) + 2\beta - 4\lambda + 3(5 - \mu) + 2(4 - \delta)$$

where

- σ is the total run time in seconds ($\sigma \leq 30.0$);
- β is the number of balls successfully transferred ($5 \leq \beta \leq 10$);
- λ is the number of balls "dropped" during the run (not in the final or initial container at the end of the run) ($\lambda \leq 5$);
- μ is the weight of the device in pounds ($\mu \leq 5.0$); and
- δ is the volume (in cubic feet) of the container (actually the cube of its longest edge dimension) ($\delta \leq 4.0$).

<u>Problem Statement (spring 2003)</u>

Each team shall design and fabricate a device that will interchange the positions of two cubic blocks approximately three inches on a side. The actual blocks will be provided for inspection in class by February 6th. The two blocks will initially be at least twelve inches apart on a provided table. The requirement for the Initial Testing is to move one block from rest and in contact with the top surface of the table to a point at least 12 inches away in less than 10 seconds. The block must come to rest on the table with the same side of the block oriented upwards as was initially oriented upwards. The device may not be initially in contact with the block, but may remain in contact after the block is repositioned on the table. (Note that this contact at the end of the run is allowed for only the Initial Testing.) The device must weigh less than three pounds. The requirement for a successful Final Testing is to interchange the positions of the two blocks such the center of mass of each moved block is within four inches of the original location of the center of mass of the other block, both blocks have the same face up as before they were moved, neither block shall have rotated (consider only the initial and final orientation) more than 45 degrees, and the movement shall have been completed in between 10 and 30 seconds. The device must weigh less than five pounds (lighter devices preferred), and be initially deployed from a six-sided container of volume less than 4.00 cubic feet (smaller containers preferred). The goal is to interchange the blocks precisely, i.e., the initial and final "picture" of the table and blocks should be indistinguishable. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = 20 - |20 - \tau| + (45 - \beta)/3 + (4 - \lambda)*5 + 3*(5 - \mu) + 5*(4 - \delta)$$

where

- τ is the total run time in seconds ($10.0 \leq \tau \leq 30.0$);
- β is the number of degrees of misalignment for the more misaligned block ($0 \leq \beta \leq 45$);
- λ is the distance in inches between initial and final centers of mass for the more poorly placed block ($0 \leq \lambda \leq 4.00$);
- μ is the weight of the device in pounds ($0 \leq \mu \leq 5.00$); and
- δ is the volume (in cubic feet) of the container (actually the block of its longest edge dimension) ($0 \leq \delta \leq 4.00$).

Problem Statement (fall 2003)

Each team shall design and fabricate a device to perform the function of a timer. The device shall function in a limited space on top of a table provided by the instructor and without operator intervention. The device shall indicate, in an obvious manner, the passage of two specified time intervals: one of thirty seconds; the other of between ten and twenty seconds. (The exact time shall be determined immediately before testing, i.e., it is variable and generally different for each device and each test run.) The device shall weigh less than five pounds and shall be deployable from a six-sided container with each edge length less than 19.0 inches (corresponding to the cube of volume 4.00 cubic feet). For all testing the device shall remain at all times within the space above the plane of the top of the table and not higher than 24 inches above the table, i.e., within the parallelepiped whose base is the table top and whose height is 24 inches. The requirement for the Initial Testing is to demonstrate a device that functions as a ten-second timer with an accuracy of plus or minus two seconds, e.g., a device that produces a specified (by the team) event between eight and twelve seconds after initiation and then "stops," i.e., all activity ceases. The device must weigh less than three pounds. There is no initial volume constraint for the Initial Testing. The requirements for a successful Final Testing are to demonstrate a device that weighs less than five pounds (lighter devices preferred), is initially deployed from a six-sided container of volume less than 4.00 cubic feet (smaller containers preferred), and functions as a timer: for 1) thirty seconds plus or minus three seconds and 2) a time to be specified between ten and twenty seconds (plus or minus three seconds). The specific time shall be determined by a random drawing just prior to the initial set up of the device. Specifically, the goal for the Final Testing is to maximize the figure of merit, FM, defined as

$$FM = 3*(3 - |30 - \tau_1|) + 2*(3 - |T - \tau_2|) + 3*(5 - \mu) + 4*(4 - \delta) \quad (1)$$

where

τ_1 is the timer indicated time in seconds for the thirty-second run ($27 \le \tau_1 \le 33$);
τ_2 is the timer indicated time in seconds for the T-second run ($T-3 \le \tau_2 \le T+3$);
T is the time in seconds to be determined for each run at the Final Testing;
μ is the weight of the device in pounds ($\mu \le 5.0$),; and
δ is the volume in cubic feet of the container (actually the cube of its longest edge dimension) ($\delta \le 4.0$).

Problem Statement (spring 2004)

Each team shall design and fabricate a device that will autonomously transfer up to eleven items from two "tubs" to a third "tub" located at least 24 inches away. The items (See Table 1 below) and the tubs will be provided (and will be available for examination), and the operations will take place on the top of a provided table. The items must be raised at least 12 inches above the tabletop (to enable the items to clear a 12-inch high barrier if there were one) during the transfer and must be placed in the receiving tub at least one second apart. The device must be deployed from a cubic container, less than 19 inches on a side and must weigh less than 5.0 pounds. The requirement for the Initial Testing is to move one of the items, the football, from rest and in contact with the top of the bottom surface of one of the tubs to a point at least 12 inches above the table and then into the receiving tub in less than 10 seconds. The requirement for the Final Testing is to transfer at least three of the items in 30 seconds

The goal for the Final Testing is to transfer as many of the items as possible within 30 seconds. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = N - 2*D + |30 - \tau| + 3*(5 - \mu) + 5*(4 - \delta) + 2*P$$

where

N is the number of items successfully deposited in receiving tub ($N \geq 3$).

D is the number of items dropped (not in a tub or in/on the device at the end).

τ is the total run time in seconds ($\tau \leq 30.0$);

μ is the weight of the device in pounds ($0 \leq \mu \leq 5.00$);

δ is the volume (in cubic feet) of the container (actually the cub of its longest edge dimension) ($0 \leq \delta \leq 4.00$); and

P is the sum of the points associated with the specific items deposited successfully. (See Table 1.)

Table 1: List of Items with their Approximate Major Dimensions and Weights

Description of Items	Major Dimension (in inches)	Weight (in ounces)	Points for Depositing*
two large rubber balls	5.5 (diameter)	6	6 each
miniature American football	6.5 (major axis)	5	8
plastic cube	3.1 (side)	4	11
orange plastic ball	3.5 (diameter)	1	4
plastic ball (initiation softball)	3.8 (diameter)	2	3
plastic ball (initiation baseball)	2.8 (diameter)	1	3
tennis ball (yellow)	2.5 (diameter)	2	3
three small balls	"golf ball sized"	<1, 1, & 1.5	2 each

* See the figure of merit (FM) above.

<u>Problem Statement (fall 2004)</u>

Each team shall design and fabricate a device that will "throw" a golf ball through an opening from a distance of at least five feet. The "opening" will be provided by the instructor and will be available for inspection in class at selected times. All other materials and the balls are to be provided by the design team. The device shall weigh less than ten pounds (the lighter the better and shall fit within a cube, 30 inches on an edge before "deployment" for the Final Testing). For the Initial Testing the opening will be a circle 7.0 ± 0.2 inches in diameter, and its horizontal centerline will be 30.0 ± 0.5 inches above the floor on which the device rests. The requirement for the Initial Testing is to successfully "throw" the golf ball through the opening in two out of three attempts (runs). For the Final Testing there will be two openings; both will be 5.0 ± 0.2 inches in diameter with centerline distances at 20.0 ± 0.5 inches and 40.0 ± 0.5 inches above the floor. The requirement for a successful Final Test is to throw five out of eight golf balls through the opening while attempting the throwing process four times at each height. The goal is to successfully "make" all eight shots using the lightest possible device which in its undeployed state would fit into a nine cubic feet cubic volume, i.e., maximize the Figure of Merit, FM

$$FM = 4*N + 3*(10 - \mu)$$

where

N is the number of successful tosses ($N \geq 5$); and

μ is the weight of the device in pounds ($0 \leq \mu \leq 10.00$).

Problem Statement (spring 2005)

Each team shall design and fabricate a device that will "propel" a golf ball over an obstacle (wall) such that the ball lands within two inches of the center of a "target" in a horizontal plane. The obstacle (wall) and the target will be provided by the instructor. (See Figure 1.) All other materials and the balls are to be provided by the design team.

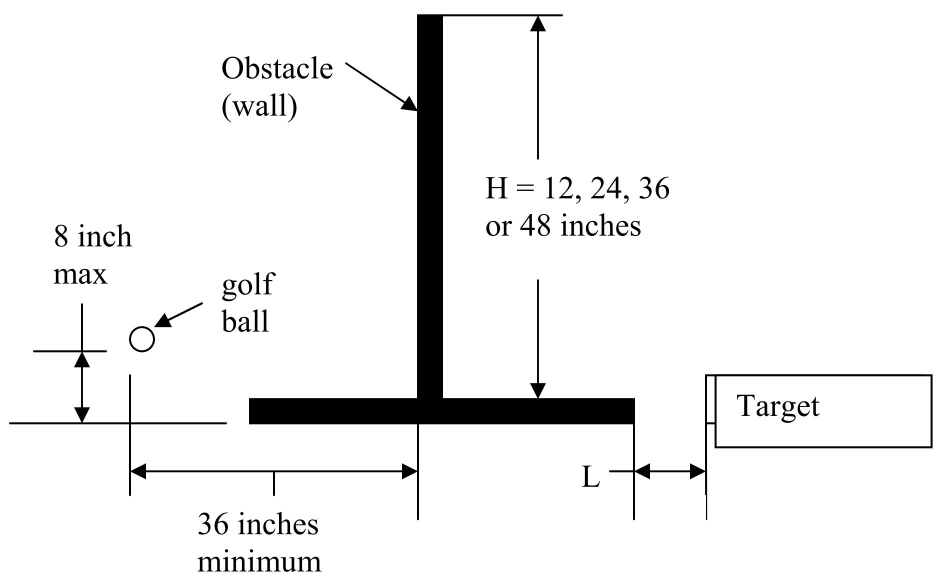


Figure 1: Schematic of the Layout

The device shall weigh less than ten pounds. The ball may not reach a height of more than eight feet above the horizontal plane of the target, and the initial placement of the ball must be at least three feet from the wall and no more than eight inches from the horizontal plane on which the target rests. For the Initial Testing the obstacle will be a 12-inch high wall and the target will be approximately 13-inches in diameter. For the Final Testing each team will select one of four wall heights (the higher the better), will place the target as close to the wall as they chose (the closer the better, but with at least 13 inches between the base of the wall and the center of the target, L = 0, in Fig. 1), and attempt to land the ball within two inches of the center of the target. (The target is a set of concentrically nested plastic flower pot saucers of various diameters filled with sand.) The requirement for a successful Final Testing is to "place" four balls in six attempts on the 13-inch diameter target for any configuration with a device that would fit within a cube, 30 inches on an edge before "deployment". The goal is to successfully project all six balls over the highest wall and place them within two inches of the center of the target which is located as close to the wall as possible, using the lightest possible device. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = 20*(N - 4) + 2*(16 - D) + 4*(10 - \mu) + 0.5*(24 - L) + 0.75*H$$

where

N is the number of times the ball lands on the target in six attempts ($N \geq 4$);
D is the sum of the "off target" distances in inches for the best four attempts;
μ is the weight of the device in pounds ($0 \leq \mu \leq 10.00$);
L is the distance in inches between the edge of the base of the wall stand and closest edge of the target (See Fig. 1); and
H is height of the wall in inches.

Problem Statement (fall 2005)

Each team shall design and fabricate an autonomous device that will separate as many as five golf balls and five ping pong balls, initially confined to a single (primary) container resting on the table, by moving them into two separate (secondary) containers. There will be no external interference with the process once it is initiated. The balls must enter each secondary container in at least one second intervals (at least one second between "ball deposits"), and the entire process has a time limit. The three containers and the table on which the testing will take place will be provided by the instructor. All other materials and the balls are to be provided by the design team. The device shall weigh less than five pounds (the lighter the better for the Final Testing) and shall fit within a cube, 30 inches on an edge before "deployment." For the Initial Testing one golf ball and one ping pong ball will be placed in the primary container. The two balls must be separated (one placed in each of the two secondary containers) in fifteen seconds. The requirement for a successful Final Testing is to properly place at least two golf balls in one of the secondary containers and at least two ping pong balls in the other in less than 30 seconds with a device occupying a volume that would fit inside a cube with the 30-inch edge before deployment. The goal is to successfully place all five golf balls in one secondary container and all five ping pong balls in the other as fast as possible (but with at least a one second interval between depositing the balls in each container) with as light a device as possible. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = G + P + 0.5*G*P - |G-P| - 2*(N-G-P) + 4*(5-\mu) + 0.1*(30-\tau)(G+P)$$

where

N is the total number of balls initially in the primary container ($N \leq 10$);
G is the number of golf balls successfully placed in the "golf ball" secondary container;
P is the number of ping pong balls successfully placed in the "ping pong ball" secondary container;
μ is the weight of the device in pounds ($\mu \leq 5.00$); and
τ is the time for the run in seconds ($\tau \leq 30$).

Problem Statement (spring 2006)

The team shall design and fabricate an autonomous device that will separate as many as 15 balls: 5 golf balls, 5 ping pong balls, and 5 other identical balls at least as large as a golf ball (to be selected by the team). There will be no external interference with the process nor external "power" provided once it is initiated. The balls are all initially placed (mixed) in a single "primary" container. (The balls can not be initially separated or placed "strategically" within this container.) The separated balls will end up in the three separate "secondary" containers and will enter them in at least one-second intervals, i.e., there will be a one-second or more delay between the balls' entrances into their respective "secondary" containers, e.g., one-second delays between the golf balls, one-second delays between the ping pong balls, etc. The requirement for the Initial Testing is to successfully separate one of each type (initially three different balls in the primary container) and place each in one of the three different secondary containers in ten seconds with a device weighing less than 5 pounds. The requirement for a successful Final Testing is to properly place at least two balls of each type in the appropriate secondary containers in less than 25 seconds with a device weighing less than 7 pounds and occupying a volume that would fit inside a cube with the 24-inch edge before deployment. The goal is to successfully place five of each type of ball in their appropriate secondary containers as fast as possible (but with at least a one-second interval between depositing the balls in each container) with a device as light and small as possible. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = G+P+O + 0.2*G*P*O - 3*(N-G-P-O) + 0.4*(112-\mu) + 0.1*(25-\tau)(G+P+O) + 0.5*(24-S)^3$$

where

- N is the total number of balls initially in the container ($N \le 15$);
- G is the number of golf balls successfully placed in the "golf ball" secondary container ($G \le 5$);
- P is the number of ping pong balls successfully placed in the "ping pong ball" secondary container ($P \le 5$);
- O is the number of "other" balls successfully placed in the "other ball" secondary container ($O \le 5$);
- μ is the weight of the device in ounces ($0 \le \mu \le 112$);
- τ is the time in seconds for the run ($\tau \le 25$); and
- S is the longest edge length of the "cube" in inches enclosing the undeployed device.

Team Problem Statement (fall 2006)

Each team shall design and fabricate an autonomous device that will separate as many as seven golf balls and seven ping pong balls, initially confined to a single (primary) container, by moving them into two separate (secondary) containers. All balls in the primary container must be transferred to one of the secondary containers, that is, any dropped or "held-up" ball nullifies the run. There will be no external interference with the process once it is initiated. The entire process should take as long as possible up to a 25-second time limit. The primary container and the table on which the testing will take place will be provided by the instructor. All other materials and the balls are to be provided by the design team. The device shall weigh less than seven pounds. For the Initial Testing two golf balls and two ping pong balls will be placed in the primary container. The four balls must be separated (Two placed in each of the two secondary containers.) in ten seconds or less. The requirement for a successful Final Testing is to properly place at least three golf balls in one of the secondary containers and at least three ping pong balls in the other in less than 25 seconds with a device weighing less than 7 pounds and occupying a volume that would fit inside a cube with the 30-inch edge before deployment. The goal is to successfully place all seven golf balls in one secondary container and all seven ping pong balls in the other as slow as possible (up to 25 seconds) with as light a device as possible. Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = G + P + 0.25*G*P - 5*|G-P| + 5*(7-\mu) + 0.1*(\tau)(G+P)$$

where

G is the number of golf balls successfully placed in the "golf ball" secondary container;
P is the number of ping pong balls successfully placed in the "ping pong ball" secondary container;
μ is the weight of the device in pounds ($\mu \leq 7.00$); and
τ is the time for the run in seconds ($\tau \leq 25$).

Examples of Individual Problem Statements

Each of these individual assignments includes detailed instructions for a written report and/or an oral presentation.. However, these requirements are not always included here due to space limitations.

Individual Problem 1

Determine your maximum short-term (say 30 seconds) mechanical "power" output. Determine your maximum long-term (say 30 minutes) mechanical "power" output. Compare your mechanical power outputs with as many other power sources as you can find including other humans. Your report should include descriptions of your "experiments" and their results, an analysis and an estimate of your "errors", and comparisons of the power outputs from various sources.

Individual Problem 2

The discipline of mechanical engineering consists of two main, yet overlapping, branches: the thermal-fluids branch and materials-mechanics branch. A large part of the thermal-fluids branch is associated with the production of mechanical power. A large part of the materials-mechanics branch is related to the mechanical transmission of this power. A widely used "sub-system" that transmits mechanical power is the drive train that in turn is composed of a variety of mechanical components, e.g., bearings, gears, couplings, and belts/chains. Each of these components has a specific purpose and is represented by a variety of special designs. Examples of bearings and gears include: ball bearings, straight roller bearings, tapered roller bearings, thrust bearings, spur gears, bevel gears, helical gears, and worm gears. Select a component or subsystem associated with either the production or transmission of mechanical power that you are particularly interested in. You are not limited to the components listed above. Obtain an example (an actual, working sample, not part of "kit", e.g., Legos) of that component (purchase it new, remove it from an existing device you have access to, recover it from a junk yard, etc.) and develop: 1) a proposal to the instructor, 2) a five-minute oral presentation for the class, 3) an extended abstract (or "take-away" sheets) to explain its use and operation that would be of interest to a high school student interested in mechanical engineering, and 4) a manned, table-top demonstration.

Individual Problem 3

Determine the "gear ratios" for all the drive gears in your car. That is, determine the ratio of the engine rotational speed to drive axle rotational speed. If you do not have a car, report on one that you can gain assess to. Prepare a short report which includes: a short description of your car, a short description of your engine, an explanation of why the transmission (the gear box) is necessary for a car, the gear ratios that you determined, a detailed explanation of how you determined these ratios, the actual gear ratios as determined from the manufacturer and an error analysis.

Individual Problem 4

Design and fabricate a device that will use the sun to determine local time in Houston, Texas, between February 6 and 8 as accurately as possible. Visit various websites or other resources to learn about the history, design and construction of such devices. Using materials and designs that will survive for a least a few weeks outside in Houston in February, design and construct:

- a vertically mounted device (for a south-facing surface) and
- a portable device for use on a horizontal surface

that use the sun for determining the local time. Both should be designed to read the time directly (i.e., without any "correction") from the position of the sun's shadow at times between 9 AM February 6 and 5 PM February 8 in Houston, Texas. (Details on the testing procedure and the grading are given in the original assignment.)

Individual Problem 5

The list below contains the first seven steps in a "design process": Recognition of a NEED, Problem IDENTIFICATION, INFORMATION gathering, IDEATION, Development of CONCEPTS, SYNTHESIS, and ANALYSIS. Use your knowledge of the conditions (physical or otherwise) on our campus (or another college campus if you prefer.) to select a "poor" situation or artifact. Use the seven steps listed above to develop a better "solution." Prepare a formal "technical report" (with a letter of transmittal) and an extended abstract of the report to describe your design process and your solution.

Individual Problem 6

Identify, describe, and discuss the five best examples of good, innovative design that you can find in your current personal experiences, i.e., that you have personally come in contact with. At least one of your examples should be on or at least very near our campus. Prepare a formal written technical report that describes in detail the two best designs and briefly describes the other three. Discuss why you selected the two best designs (What were the reasons for your choice?) and identify any applicable US patents associated with these designs. Select your single best example and prepare a formal, five-minute, oral presentation to present and discuss it. Also, prepare an extended abstract that can be printed on two sides of a single (8½ x 11) sheet that illustrates and describes your single best design and explain why you believe it to be an excellent design Your audience for this assignment is a mechanical engineering student peer. Prepare an interim report to the instructor in the form of a formal business letter briefly describing the five good designs you have selected and provide one good reason for each selection. This letter is limited to two pages. Feedback on your choices will be provided for use in preparing your other reports.

Results for Two Team Projects

Separate golf balls from ping pong balls

A summary of the results from the Fall 2005 team project is given below. Example solutions are seen in Figs. 2 through 5 and the grading is summarized in Table 2. Figures of Merit for all sixteen teams ranged from 13 to 63 with an average of 42. All grading has been converted to the grade point scale, i.e., 0 to 4.0 with 4.0 =A, 3.0 = B. etc. Comments on the design are given in column 2. At the Final Testing (column 3) the first solution weighed 4.5 pounds, sorted all ten balls (G+P=10) in 11.8 seconds which resulted in a figure of merit (FoM in column 4) of 63 which was an outstanding result (an A+ grade) (Test = 4.3 in column 5). The instructor's evaluation of the solution is given in column 6 (Eval). The grade for the reports is given in column 7 (Comm.). The overall project grade (column 8) was determined by combining the grades for the three components (25% for Test. 25% for Eval, and 50% for Comm). Each of the first two projects earned an "A"; the third, a "B+", and the fourth, a "B-".

Figure 2: Spring lifter, size sorter, pendulum timer

Figure 3: Gravity lifter, size sorter, electric timer

Figure 4: Gravity lifter, pachinko timer-sorter

Figure 5: Spring lifter, pendulum timer size sorter

Table 2: Grading of Devices in Figures 3 through 6 (Fall 2005)

1	2	3	4	5	6	7	8
	Comments on Designs	**Comments of on Final Testing**	**FoM**	**Test ***	**Eval ***	**Comm ***	**Project Grade***
Spring lifter	spring lifter, pendulum timer	4.5 lbs, G+P=10, 11.8 sec	63	4.3	3.9	3.6	3.9
Gravity lifter	gravity lifter, electric timer	6.5 lbs, G+P=10, 12.5 sec	54	3.9	3.7	4.1	3.9
Pachinko	Nicely crafted, not reliable	7.0 lbs, G+P=7, 9.2 sec	43	3.4	2.9	3.6	3.4
Spring lifer	Nice timer, not reliable	9.9 lbs, G+P=9, 13.0 sec	23	2.2	2.3	2.0	2.6

* based on a 4.0 grad point scale

<u>Throw golf balls at a target</u>

A summary of the results from the Fall 2004 team project is given below. Example solutions are seen in Figs. 6 through 9 and grading is summarized in Table 3 as they were for Table 2. Figures of Merit ranged from 0 to 64 with an average of 32 for 16 teams. As described above all grading was converted to the grade point scale, i.e., 0 to 4.0 with 4.0 =A, 3.0 = B, etc. In Table 3 the overall project grades for the four examples were A, B, B+, and A, respectively. During the Final Testing the first solution weighed 1.1 pounds and successful projected all eight golf balls through the openings (N=8), four through each (comments in column 3).

Figure 6: Torsion Spring Solution

Figure 7: Testing Set Up with Pendulum Solution

Figure 8: Compression Spring Solution

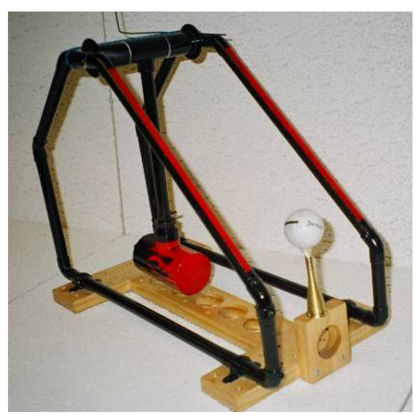


Figure 9: Pendulum Solution

Table 3: Grading for Devices in Figs. 6 through 9

1	2	3	4	5	6	7	8
	Comments on Designs	**Comments of on Final Testing**	**FoM**	**Test ***	**Eval ***	**Comm ***	**Project Grade***
Torsion Spring	Too powerful, non-gravity	1.1 lbs, N=8	66	5.0	3.4	3.7	4.0
Pendulum	Robust, gravity	8.3 lbs, N=6	29	2.7	3.5	2.8	3.0
Comp. Spring	Non-gravity	7.2 lbs, N=6	32	3.3	3.4	3.6	3.5
Pendulum	Accurate, gravity	5.3 lbs, N=8	46	4.2	4.1	3.8	4.0

* based on a 4.0 grad point scale

Results for Two Individual Problems

<u>The Drive Train</u>[43]

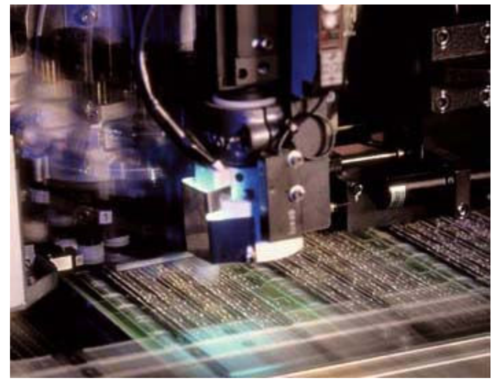
The project was assigned in the fall of 2003. Forty-two solutions (Table 4) were submitted in the class of 43. An example of the two-page take-away sheet (extended abstract) is shown in Fig. 10. Each of the two studio sections was divided into two groups, say A and B. During each three-hour studio each member of groups A and B took turns for a 90-minute period of 'manning' a table in the lobby of the engineering building while demonstrating his project to all who stopped. While members of group A demonstrated their projects, members of group B were the audience. Then they switched roles. The same was done for the other studio.

Table 4: The Forty-two Projects

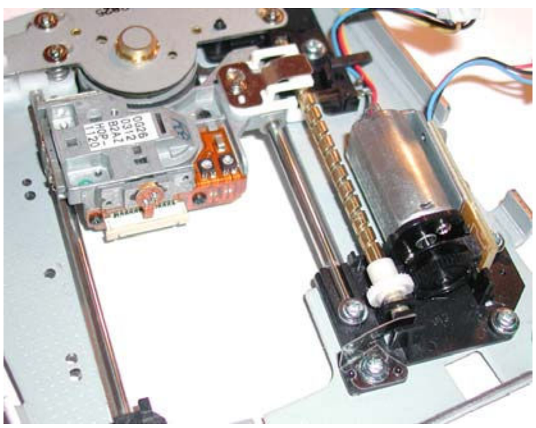
Various clutches	6
Transmissions	4
Ball bearings	3
Worm gears	3
CV joints	2
Gears	2
2-stroke engines	2
Belt drive systems	2
Universal joint	1
Compressor (piston)	1
Slider-crank mechanism	1
Servo	1
Windshield wiper system	1
Laser/lens system for a CD	1
Rotary engine	1
12-speed bike gear	1
Differential	1
RPM transmitter	1
Fuel injector system	1
Oscillating sprinkler	1
Propeller	1
Flywheel	1
Garage door opener	1
Bevel gear	1
Planetary gear	1
4-stroke engine	1

Worm Gears

Precision linear movement:



Worm Gears are used in all sorts of machinery that require precise linear movement. Linear movement with a worm gear is achieved by turning a worm gear that passes through a grooved hole in a device that slides along a track. CD Players use such a setup to precisely move the lens and laser over the surface of a CD. Robotic manufacturing equipment, like soldering machines and circuit board assemblers (chip shooters), use worm gears to achieve extremely precise placement. Linear actuators, used in many different applications in place of bulky hydraulics or pneumatics, operate by a worm gear generally.



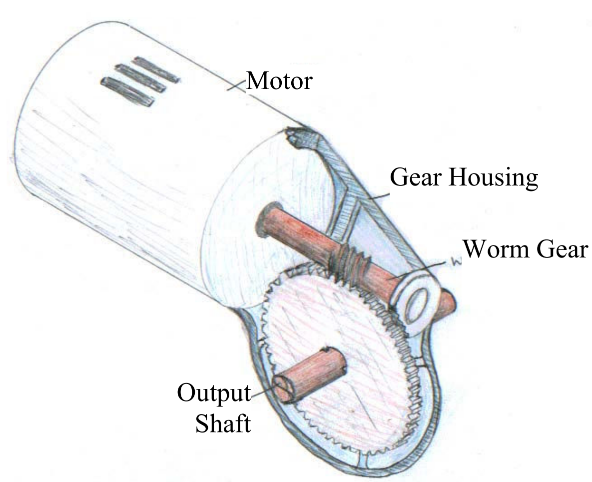
High gear ratios and non back drivable:

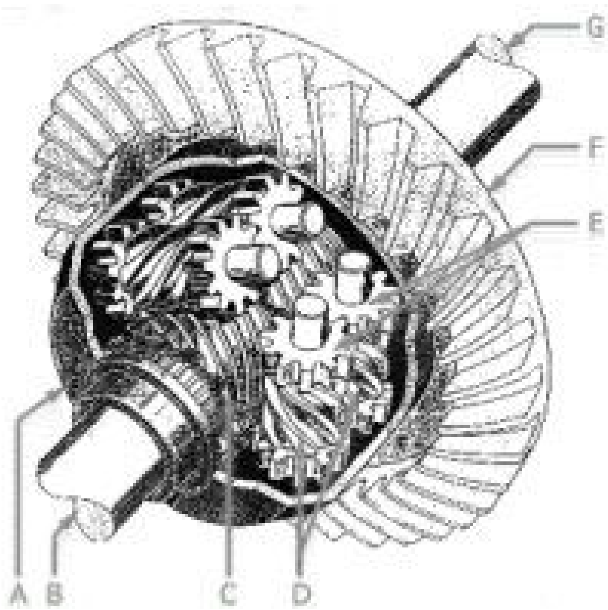
Worm gears are also used to gear down motors. High gear ratios can be achieved with a single worm gear, anywhere from 8:1 to 300+. Another advantage of the worm gear is its inherent resistance to back driving, meaning that the worm gear can turn another gear but another gear cannot be used to turn the worm gear. This makes the worm gear ideal for situations where movement is not wanted unless the motor is turning. Car seats and window motors use a worm gear to achieve the high reduction ratio needed and to prevent back driving (you cannot push a car window down yourself).

Another Example:

Another place you can find worm gears are in differentials for some cars. A type of differential, called a Torsen differential, can be found in some high end cars, particularly all wheel drive (Audi Quattros use these). Torsen differentials utilize worm gear's resistance to back driving in order to control torque distribution and help prevent wheel slippage.

Cutaway view of Worm-geared Motor





Torsen Differential

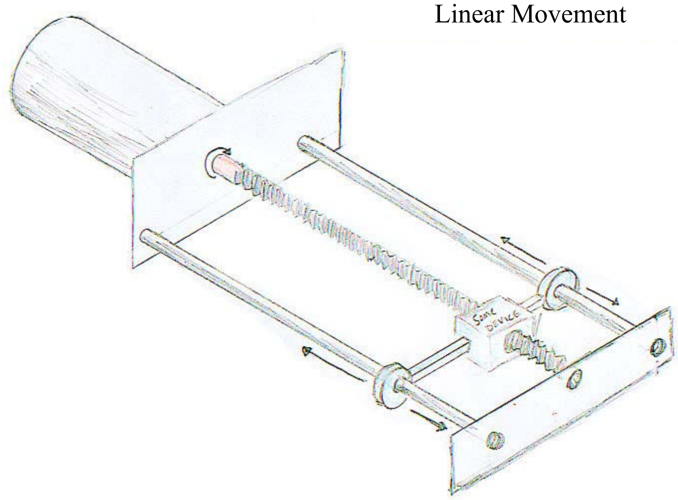
Some places where you can find a worm gear:

Many devices encountered in everyday life have worm gears in them. Here are some things you might have used.

- Hospital beds (linear actuator)
- Hand held electric mixers
- Car seat motors
- CD Players and DVD Players
- VCRs
- Window Motors
- Torsen Differentials (in some cars)
- Cameras

When would you use a worm gear?

Turning Rotational Movement into Linear Movement



Any time a high gear ratio is needed and space is limited. The gear ratio depends on how many teeth are on the gear that the worm is turning. When a non back drivable mechanism is desired, a worm gear is a good choice. Worm gears are capable of transferring large amounts of torque, and they do not take up a lot of space. Also a worm gear can be used when it is necessary to shift the angle of the power source by 90°. However, because of the way the teeth of a worm gear slide along the teeth of a meshing gear, efficiency of a worm gear is slightly less than that obtained by other means (such as using a planetary gear system). If high efficiency is a concern, then using a worm gear to transmit power is not such a good idea.

If linear accuracy is needed then a worm gear (linear actuator) is also useful. There are several ways of producing linear movement from rotational energy, but none are as accurate as the worm gear method. Here are some other methods for linear movement:
Pulley and belt - belts stretch and slip
Rack and pinion - gears have backlash
Hydraulics and pneumatics - position cannot be controlled accurately

Figure 10: Worm Gear Take-Away Sheet

Shortly after the Drive Train project was completed a short survey was administered. Table 5 summarizes the results of that survey. The students were asked to indicate a response on a Likert scale from “strongly agree (5)” to “strongly disagree (1)” for the seven statements listed on the left. The average (calculated by dividing the sum of the products of the number of responses in each category and the “value” of that category, i.e., 1, 2, 3, 4, or 5, by the total number of responses for that statement) of the responses was determined for each statement for six groups of respondents. The six columns refer to these six groupings: column 1 is the response from the whole class (41 responses, there were 43 students in the class); columns 2 and 3 are the male and female responses, respectively; columns 4 through 6 are Caucasian, Hispanic, and other minorities, respectively. Note particularly the strong support for a “Learning Laboratory” (statement #7) by all (but especially females [column 3] and Hispanic [column 5]) and the “steep” learning curve experienced by the females. (Ten of the eleven female students “strongly disagreed” (The eleventh simply “disagreed”.) that they had “considerable previous experience” with their component (statement #5), and yet as a group they provided the strongest agreement that they “learned a lot.” (statement #2)) .

Table 5: Results from Students’ Survey for the Drive Train Project

	Please respond to the following statements indicating the degree to which you agree:						
	5= strongly agree; 4=agree; 3=neutral; 2=disagree; 1=strongly disagree.						
	Group (Defined below)	**1**	**2**	**3**	**4**	**5**	**6**
	Number of responses from each Group	**41**	**30**	**11**	**17**	**14**	**10**
1	This was a worthwhile project.	3.83	3.87	3.73	3.94	3.64	3.90
2	I learned a lot from doing this project.	4.10	3.93	4.55	4.00	4.00	4.00
3	I enjoyed learning on my own.	3.88	3.93	3.70	3.94	3.77	3.90
4	I enjoyed sharing my knowledge about my project with others.	3.98	4.03	3.82	4.12	3.86	3.90
5	I had considerable previous experience that was useful in completing this project.	2.85	3.50	1.09	2.82	2.64	3.20
6	I knew very little about the topic of my project before this semester started.	2.95	2.27	4.82	3.24	2.79	2.70
7	I think the Department should have a hands-on “learning laboratory” where students could “interact” with other such artifacts	4.29	4.17	4.64	4.24	4.57	4.00
	Groups: 1=entire class; 2=male; 3=female; 4=Caucasian; 5=Hispanic; 6=Minority (4 Af-Am, 3 Mid-East, 2 Asian, 1 Pac Is)						

The Sun Clock[44]

In the spring 2003, thirty-eight students submitted artifacts, both horizontally mounted and vertically mounted sun clocks. Table 6 summarizes the test results. The average error was around an hour, and 63% of the sun clocks were within an hour of the correct time. The most common large error was reversing AM and PM. Photographs of representative artifacts are shown in Figs. 11 through 15. Figures 11, 12 and 13 present what could be described as “extraordinary” examples. The student who produced the artifact in Fig. 11 worked in the metal forming shop and built it from “scrap.” The artifact in Fig. 12 was built from “found” parts. The student who produced the artifact in Fig. 13 owned a company that makes etched glass displays. Descriptions of the remaining artifacts are included in the figure captions.

Table 6: Time Measuring Error for Sun Clocks

	H*	V**
Mean Square Error (minutes)	49	75
Number of Devices with AM/PM Error	4	5
Number of Devices within 15 Minutes	9	9
Number of Devices within 30 Minutes	17	12
Number of Devices within an Hour	27	21

*horizontal sun clock

**vertical sun clock

Figure 11: One of the best horizontal sun clocks (5 minutes “slow”)

Figure 12: One of the most impressive looking horizontal sun clocks but more than an hour fast

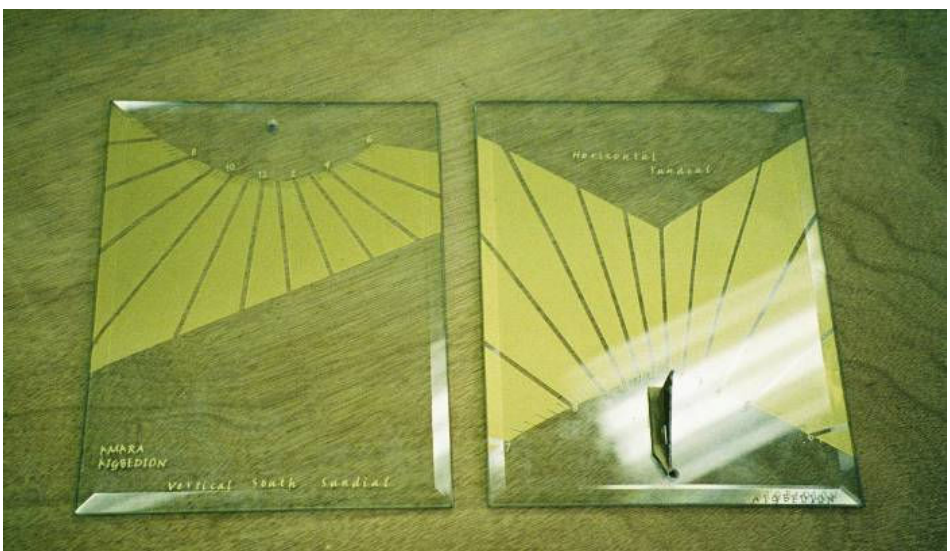


Figure 13: A matching set of sun clocks etched on glass. The horizontal device (on the right) had essentially zero error, but the other was about 40 minutes slow. Note the non-symmetry to allow a direct reading on February 6 to 8.

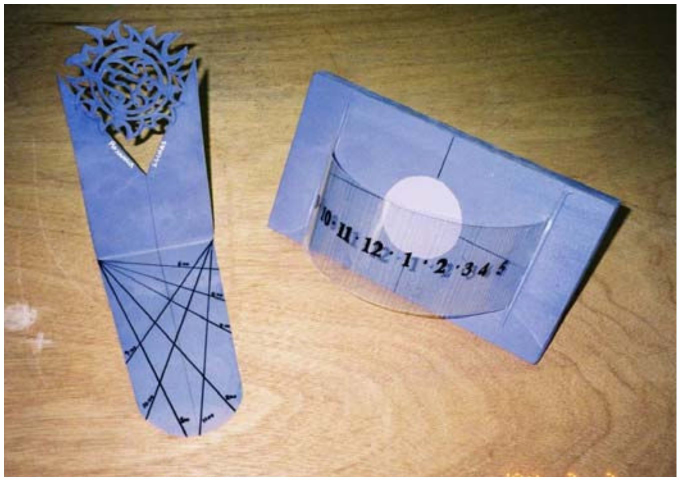


Figure 14: Interesting simple devices but both reversed AM and PM.
The vertical sun clock on the right produced an image (shadow)
of the appropriate number on the "spot".

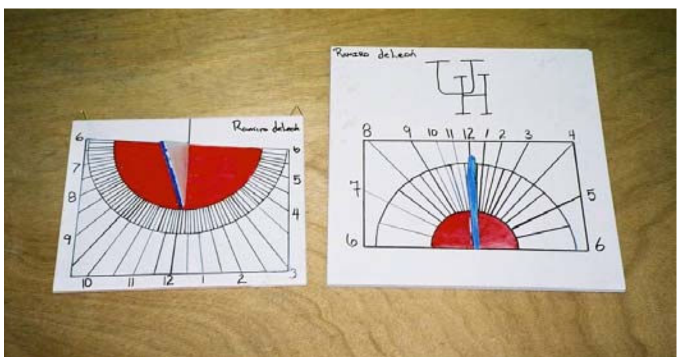


Figure 15: Two sun clocks drawn on sections of glazed tile.
The vertical device on the left was correct within minutes,
but the other was about 45 minutes fast.

Student Survey

As part of the end-of-the-semester survey, the responses (using a five-point Likert scale) to seven common statements are given in Table 7 for seven semesters, fall 2002 through fall 2005. It is seen that the students fairly strongly support the premise that the three primary objectives of the course are being met (designing, teaming and communicating). Only 3% indicated that they did not improve their abilities in these areas. It is also clear that they enjoy "hands-on" projects and working in teams (despite the occasional teaming issue). There are some who believe that competition is a "bad thing" leading to unwelcome ego issues, but this premise seems not to be shared by the students as less than 5% do not "enjoy the friendly competition between teams". One of the more interesting responses is the last one which seems to indicate that there is a real interest by over 87% of the students to "learn" more about the solutions of others even though there is clearly no benefit to their grade.

Table 7: Results from End-of-the-Semester Class Survey (Fall 2002 through Fall 2005) (5 indicates the students "strongly agree" with the statement; 4 indicates, "agree"; 3 indicates, "neither agree nor disagree"; 2 indicates, "disagree"; and 1 indicates, "strongly disagree"; N is the number of responses; and "avg" is the average of the responses.

1	2	3	4	5	N	avg	I feel that I improved my ability to
			140	132	300	4.31	design a system or component to meet desired needs
	9	31	129	131	300	4.27	function on a team
1	11	57	143	88	300	4.02	communicate effectively
							I enjoyed
3	7	22	99	169	300	4.41	working on the projects
8	11	35	99	147	300	4.22	working on a team
1	13	31	94	161	300	4.34	having friendly competition between teams
2	6	30	85	177	300	4.43	seeing how others solved problems I struggled with

Conclusions

This paper has presented an overview of both team and individual projects over a five-year period from 2002 through 2006 in an early design course. Each of ten, semester-long team projects required the design, fabrication and testing of an artifact. Of the six individual projects described, two were experimental, one required reverse engineering, one was hands-on, and two were related to design evaluation and the design process. Example results were given for two of the team projects and for two of the individual projects. The student survey results indicated that engineering students enjoy working on hands-on projects and competing with their peers, and even learn from the experience.

Bibliography

1. Daniel Raviv, "Teaching 'Hands-on' Inventive Problem Solving," Proceedings of the 2001 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
2. Michael Lobargh, "Revving Up 'Hands-on' Engineering", Proceedings of the 2004 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
3. Michael J. Prince and Richard M. Felder, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases," Journal of Engineering Education, Vol 95, No. 2, pp. 123-138, April 2006.
4. S. C. York, Dave Confer, Jeff Connor and Mike Gregg, "Design and Implementation of a Fuel Cell Laboratory Experience for Freshman Engineering Students," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.

5. James Bales, and Thomas Consi, "Smart Rockets: A 'Hands-on' Introduction to Interdisciplinary Engineering", Proceedings of the 2003 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
6. Ralph Budwig, Matthew Cunnington, Donald Elger, Steve Beyerlein, and Levi Westra, "Design of a Wind Tunnel Facility for 'Hands-on' Use by Beginning Engineering Students," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
7. Jeffrey Connor and Jean Kampe, "First Year Engineering at Virginia Polytechnic Institute and state University," A Changing Approach," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
8. Jeffrey Connor and Richard Goff, "Assessment of Providing In-Class, 'Hands-on' Activities to Virginia Tech First Year Engineering Students," Proceedings of the 2001 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
9. William Durfee, "A 'Hands-on' 'Introduction to Engineering' Course for Large Numbers of Students," Proceedings of the 1999 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
10. Douglas G. Schmucker, "Authentic Engineering Design in a Freshman "Transition to College" Course," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
11. James A. Newell, "If You Let Them Build It, They Will Come: 'Hands-on' Projects for Freshman to Enhance Student Learning," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
12. Robert Borchert, Daniel Jensen, and David Yates, "Development and Assessment of 'Hands-on' and Visualization Modules for Enhancement of Learning in Mechanics," Proceedings of the 1999 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
13. J. Roger Parsons, Christopher D. Pionke, Elaine J. Seat, Fred Weber, and Daniel C. Yoder, "Integration of Statics and Particle Dynamics in A Hands-On Project-Oriented Environment," Proceedings of the 1999 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
14. Flynn L. Auchey, John C. Duke, M Siegfried, and Jack Lesko, "'Hands-On' Statics Integration Into an Engineering Mechanics-Statics Course: Development and Scaling," Proceedings of the 1999 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
15. Douglas Cleary, Eric Constans, Jennifer Kadlowed, Beens Sukumaran, and Paris von Lockette, "'Hands-on' Learning Tools for Engineering Mechanics," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
16. Francis Di Bella, "Using a 'Hands-on' Engineering Technology Approach to Conducting Statics and Dynamics Lab Courses, Proceedings of the 2004 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm
17. James Klosky and Reid Vander Schaff, " 'Hands-on' Demonstrations in Introductory Mechanics," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
18. Chiang Shih, "The Development of a Dynamic Systems Laboratory and the Implementation of Learning through Teaching Concept", Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
19. Ganapathy Narayanan, "Inclusion of 'Hands-on' Interactive Programs for Teaching Statics," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
20. Allison M. Okamura, Christopher Richard, and Mark R. Cutkosky, "Feeling is Believing: Using a Force-Feedback Joystick to Teach Dynamic Systems," Journal of Engineering Education, Vol. 91, No. 3, pp. 345-350, July 2002.

21. Chris Kobus and Gilbert Wedekind, " A Unique Liquid-Vapor Thermodynamic Property Measurement Apparatus, Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
22. Rajendra K. Bordia, Scott Grove, Vipin Kumar, and Johon E. Weller, "The Development of a Project-Based Introduction to Manufacturing Laboratory Involving a Stirling Engineering", Proceedings of the 1998 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
23. Ann M. Anderson and Richard D. Wilk, "The Use of 'Hands-on' Table Top Laboratories in Undergraduate Thermal-Fluid Science Course," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
24. James C. Hermanson and David J. Olinger, "Implementation of Integrated Thermo-Fluid Experiments in WPI's Discovery Classroom," Proceedings of the 2000 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
25. David J. Olinger and James C. Hermanson, "Integrated Thermal-Fluid Experiments in WPI's Discovery Classroom." Journal of Engineering Education, Vol. 91, No. 2, pp239-244, April 2002.
26. Robert Edwards, "A Simple Hairdryer Experiment to Demonstrate the First Law of Thermodynamics," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
27. Youakim Al Kalaani, "A Solar System Project to Promote Renewable Energy Education," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
28. Y.-X. Tao, M. Zampino, Y. Cao, W. Bao, R. Moreno, G. Calderon, M. Rivera, M. Vargas, and D. Chavez, "Using Design, Build and Test Projects for Improving the Design of Fluid-Thermal Systems and HVAC Design," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
29. Donna Dorminey and Shad Reed, "Designing Experimental Procedures: A Low Cost, 'Hands-on' Project that Students Actually Enjoy," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
30. Odis Griffin, " 'Hands-on' 24/7 – Virginia Tech's Jose F. Ware, Jr., Advanced Engineering Laboratory", Proceedings of the 2004 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
31. Rahul Bargava, Howard M. Choset, Amy Graveline, and Michael Rosenblatt, "Designing and Implementing 'Hands-on' Labs for an Introductory Robotics Course", Proceedings of the 2000 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
32. Steve Sternberg, " 'Hands-on' Classroom Learning in Material Engineering," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
33. Saeed Foroudastan and Ian Campbell, "Student Projects: 'Hands-on' Experience with Mechanical Engineering Technology," Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
34. Mario Medina and Louis Thurston, "On the Use of Equation Solvers, Interactive Software, and 'Hands-on' Projects in Integrated Sophomore Engineering Courses," Proceedings of the 2003 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
35. Frederick Stern, "Development of 'Hands-on' Student Experiences with Modern Facilities, Measurements Systems, and Uncertainty Analysis in Undergraduate Fluids Engineering Laboratories," Proceedings of the 2004 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
36. Donald Weiss and Peter Weiss, " 'Hands-on' Project to Engage Non-Engineering Students," Proceedings of the 2001 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
37. Nathaniel Blair, Timothy Benson, Paul Berke, Dale Corlew, John Kruoczak, Kristen Lantz, Daniel Lappenga, Matthew Scholtens, and David Woessner, " 'Hands-on' Laboratory Projects for Non-

Science Majors: Learning Principles of Physics in the Context of Everyday Technology," Proceedings of the 2002 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.

38. Rachel Speaks, "'Hands-on' Engineering for High School Students", Proceedings of the 1998 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
39. Barbara M. Adams, Janet Sharp, Rebecca Sidler Kellogg, and Loren Zachary, "Providing Meaningful 'Hands-on' Experiences in Engineering Modelling the Process with 8-12 Educators", Proceedings of the 2001 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm.
40. Cordelia Brown, "Incorporating Engineering Concepts in the Middle School Science Classroom", Proceedings of the 2005 ASEE Annual Conference and Exposition, Available on Conference CD and Search at http://www.asee.org/about/events/conferences/search.cfm
41. Richard Bannerot, "Experiences in Teaching Sophomore Design in Mechanical Engineering," Proceedings of the International Conference on Engineering Education 2004: Global Excellence in Engineering Education, Gainesville, FL, October 16-21, 2004. Available on Conference CD and posted at conference website: http://succeednow.org/icee/SessionIndex.html.
42. R. W. Brown, "Autorating: Getting Individual Marks from Team Marks and Enhancing Teamwork," 1995 Frontiers in Education Conference Proceedings, Atlanta, GA, November 2-4, 1995, available at http://fie.engrng.pitt.edu/fie95/3c2/3c24/3c24.htm
43. Richard Bannerot, "An Early Hands-on Experience in Mechanical Engineering that Seems Particularly of Interest to Female Students," Proceedings of the 2005 Annual Conference of the ASEE Gulf Southwest Section, March 23-25, 2005, Texas A&M University – Corpus Christi, Corpus Christi, TX, paper T4A4 on CD. http://www.me.unm.edu/~khraishi/
44. Richard Bannerot, "A Sun Clock Project," Proceedings of SOLAR 2006 National Conference and Exhibition, July 8-13, 2006, Denver, CO. Available on conference CD, Paper 0043.

APPENDIX I: Sample of Major Team Design Project Description

MECE 2361: Mechanical Engineering Design I

August 22, 2005

Major Team Design Project

Form Teams:	September 12th
Initial Testing:	October 3rd
Final Testing:	October 26th
Presentation and Evaluation:	November 16th
Progress Reports:	September 28th and October 19th
Final Report and Ext. Abstract:	November 9th

PROBLEM STATEMENT

Design, fabricate and test an autonomous device that will separate as many as five golf balls and five ping pong balls, initially confined to a single (primary) container, by moving them into two separate (secondary) containers. There will be no external interference with the process once it is initiated. The balls must enter each secondary container in at least one second intervals (at least one second between "ball deposits"), and the entire process has a time limit. The three containers and table on which the testing will take place will be provided by the instructor. All other materials and the balls are to be provided by the design team. There shall be two tests of the device: Initial Testing on October 3rd and Final Testing October 26th. For both tests the device shall weigh less than five pounds (the lighter the better for Final Testing) and for the Final Testing shall fit within a cube, 30 inches on an edge before "deployment."

For the Initial Testing one golf ball and one ping pong ball will be placed in the primary container. The two balls must be separated (one placed in each of the two secondary containers) in fifteen seconds. For the Final Testing each team will select the number and type of balls to be placed in the primary container. It is required that at least two identical balls be placed in each of the secondary containers within 30 seconds. It is desired to transfer as many balls as possible (up to ten; five into each secondary container), as fast as possible, with a device weighing as little as possible. However, there will be point deductions for balls not transferred successfully and for inequalities in the numbers of each type of ball transferred. The scoring will be determined by calculating a figure of merit from the given relationship.

There is no restriction on the type of energy used, but there can be no external (outside the allowed volume) power source. However, designs using gravitational energy will be viewed more favorably than those using other forms of energy. Devices using "mechanical" energy will be viewed second most favorably. Further, if multiple forms of energy are used, the greater the proportion of gravitational and/or mechanical energy the better. Batteries are allowed but chemical explosions are not. Safety is of utmost importance, both to the people constructing and operating the device, and to those observing its operation. "Unsafe" devices will be disqualified, and "safe" devices will be rated higher than those judged to be less safe.

The team must demonstrate that its device satisfies the constraints during its Presentation on November 16th to qualify for "full credit" in the design evaluations that will be conducted after the Presentations. Details on the constraints, goals, documentation and evaluation process are given in this document.

TEAMS

Teams of four students each shall self-form before class on September 12th. All students not in teams by the 12th will be placed in teams by the instructor. All team members must be able to attend the same Wednesday studio session, i.e., afternoon or evening. Teams of three may be necessary if the total number of participants is not a multiple of four. In unusual circumstances the instructor may form non-standard teams. Each team shall declare a name and establish a spirit that should be demonstrated in the esthetics of the device, presentations and reports. The proposed team names will be submitted to the instructor before leaving class on September 12th. Team names may be changed at any time with the consent of the instructor.

THE DEVICE

Under no circumstances shall the device in any way cause harm to the operators or the audience or damage to the room or its contents.

For the Final Testing and at the Presentation, the device shall be initially confined within a cubic volume, thirty inches on each edge. The device should be designed so that it may be weighed on a simple "pedestal scale" (available for inspection upon request). For the Final Testing the weight of the device must be less than five pounds, the lighter the better, as defined by the Figure of Merit in Eqn. (1). Additional goals for the device are defined in the Final Testing section.

For the Initial Testing there is no volume constraint. The weight of the device must be less than five pounds.

The "mechanical" subsystems of the device must be constructed by the members of the team but may contain prefabricated mechanical components such as gears, hinges, pulleys, wheels, bearings and shafts. However, no "kits" are allowed. Gear boxes must be constructed from individual gears, but they can be purchased as a set. "Vehicles" must be constructed from individual parts, e.g., wheels and axle parts, i.e., not from kits or toys. Normal, simple fasteners such as screws, nails, bolts, rivets, tape, glue, etc. may be utilized. Fabricated commercial parts (components and assemblies) may not be used "for their intended purpose" in the device, but may (with the instructors specific approval) be incorporated into the device if they are NOT being used for their intended purpose, e.g., a automobile radio antenna can be used as a structural component but it can not be retracted to reduce its length so that it will fit into the container (since it was intended to be retractable). Exceptions will be discussed in class. All questionable components should be submitted to the instructor before being incorporated into the device. A team that uses an unauthorized or illegal component or subsystem will be given a "failure" for the test or run in which this component or subsystem is utilized.

No "sticky material" (e.g., tape) is allowed to hold the device or the containers in place, although suction cups and friction mats are acceptable. Nothing is allowed to penetrate the table, e.g., tacks. All parts of the device must remain above the horizontal plane of the table, e.g., no clamps permitted over the edge of the table. No damage (either physical or esthetic) shall be inflicted on the table, the room or its other contents.

OPERATIONS

The three containers will be available for inspection during class on August 29th and subsequent classes and will be provided to the team just prior to "set up" for the testing. There is no restriction on the placement of the balls in the initial container or on the placement of the containers except that they must be placed initially upright on the table. The primary container may be moved during the test; the two secondary containers should not be moved. For both the Initial Testing and the Final Testing, at the direction of the timekeeper, a team member will be instructed to initiate the operation of its device. The initiation shall be in the form of a simple "release" and shall not transfer any energy to the device, the containers, or the balls. It is expected that some thought will be given to using an innovative release mechanism, at least for the demonstration during the Presentation. Just prior to release, contact is allowed only with the "release mechanism" (No other part of the device may be contacted by a team member.) and after the release no human (or animal) contact with the device, the table, the balls, or the containers will be permitted. The operations end after fifteen seconds for the Initial Testing, when the team announces termination (30 second time limit) of the Final Testing, or, in either test, when the instructor determines that the attempt has been completed.

The objective is for the device to "perform" in as creative and interesting a way as possible. The desired attributes of a "creative" performance are:

- to demonstrate innovative concepts to initiate the motion, to maintain the motion, and to control the motion,
- to utilize spectacular events,
- to keep the attention and interest of the audience, and
- to surprise, entertain, and excite the audience.

TIMES AND PLACES FOR THE TESTING AND PRESENTATION

The Initial Testing will take place in the regular Monday meeting room during the regular meeting time on October 3rd. The Final Testing will be take place in the lobby of the Engineering Building (D) on Wednesday, October 26th beginning at 1 PM and 5:30 PM for the afternoon and evening studios, respectively. The testing and evaluation criteria for both the Initial Testing and the Final Testing are discussed in the next two sections. The Presentations for the project will be in the regular Wednesday meeting rooms during the regular meeting times on November 9th.

INITIAL TESTING

The requirement for the Initial Testing is to successfully separate the two balls by removing them from the primary container and placing each in a different secondary container. The team shall have two minutes to set up and perform any "practice" tests. Each team will be given two testing opportunities or runs (if necessary) in the Initial Testing for full credit. (A team is allowed only one test for each "set up".) Two additional testing opportunities will be allowed (for less credit, see the Grading Section of this document) for those devices that are unsuccessful in both of the first two tests. Teams unsuccessful in meeting the stated requirements after four tests (total) will be allowed to meet with the instructor <u>once</u> (at a mutually agreed upon time and place) to demonstrate a successful Initial Testing before 5:00 PM on October 10th. Failure to perform a successful Initial Testing by this time will result in disqualification of that team from the Final Testing. In this event, the team should continue to comply with all project deadlines and plan to participate in the Presentation.

The order of testing will be determined by the instructor and announced at the beginning of the Initial Testing. Any team not present, ready to test at the beginning of the testing period may not be allowed to participate in the Initial Testing and in that case will be treated as if it failed all four tests as discussed above. After one team has removed its device, the clock starts for the deployment of the next device. There is a limited time for deployment (two minutes) and removal (thirty seconds), and a team will be disqualified for that test should it not comply.

FINAL TESTING

Teams that satisfy the Initial Testing requirements before 5 PM on October 10th as described above will qualify for the Final Testing which will take place on October 26th, beginning at 1:00 PM (afternoon studio) and 5:30 PM (evening studio) in the lobby of the D-building. Teams must be present with their devices, ready to test, at 1:00 PM and 5:30 PM, respectively, to be eligible for the Final Testing. The testing may take more than three hours. Teams should make arrangements to continue Testing beyond 4:00 PM and 8:30 PM if necessary. If a device that has not been successful (see next paragraph for the definition of "successful") by 4:00 PM or 8:30 PM and if a representative of the team cannot be present to continue the Final Testing, the Final Testing will be declared "unsuccessful" for that device.

The requirement for a successful Final Testing is to properly place at least two golf balls in one of the secondary containers and at least two ping pong balls in the other in less than 30 seconds with a device weighing less than 5 pounds and occupying a volume that would fit inside a cube with the 30-inch edge before deployment. Teams will bring their devices to the common testing area and will be allowed two minutes to set up, practice, place the balls (up to ten) in the container, and locate the three containers on the table. Failure to meet this time constraint and being unprepared to "start" on time will result in the failure for this attempt. The goal is to successfully place all five golf balls in one secondary container and all five ping pong balls in the other as fast as possible (but with at least a one second interval between depositing the balls in each container) with as light a device as possible.

Specifically, the goal is to maximize the figure of merit, FM, defined as

$$FM = G + P + 0.5*G*P - |G-P| - 2*(N-G-P) + 4*(5-\mu) + 0.1*(30-\tau)(G+P) \qquad (1)$$

where

N is the total number of balls initially in the primary container ($N \leq 10$),
G is the number of golf balls successfully placed in the "golf ball" secondary container.
P is the number of ping pong balls successfully placed in the "ping pong ball" secondary container.
μ is the weight of the device in pounds ($\mu \leq 5.00$),
τ is the time for the run in seconds ($\tau \leq 30$)

A figure of merit will be determined only for devices achieving successful Final Testing as defined above, i.e., depositing at least two of each balls successfully. There will be two rounds of testing without penalty and additional rounds of testing with increasing penalties for the initially unsuccessful devices. Only the highest figure of merit achieved for a given round will be used, i.e., not the average for both rounds. If the device is unsuccessful in the first round, it must be removed and presented again for Final Testing in the second, and if necessary subsequent, rounds. Minor repairs are allowed between rounds, but if significant changes are made to the device and/or significant material is added, the judges may require that the device be reweighed and measured as in the initial round. Otherwise, after two rounds leave the device "set up" for the future rounds, i.e., no need to deploy the device from the restricted volume after the second round.

The testing order will be announced by the instructor immediately before the testing session. Teams that fail to achieve a successful test in the either of the first two rounds will be allowed to participate in up to two additional rounds under the conditions described above. However, the resulting figures of merit will be reduced by 25% per round, and the device will not be eligible for bonus points. (See the Grading Section on page 7.) The order of testing shall remain the same. Devices that are unsuccessful after a total of four rounds will receive no credit (zero) for Final Testing.

REPORTING

There are a total of four written documents required, two progress reports, a final report, and an extended abstract. The due dates for these reports are listed on the first page of this document.

Progress Reports: Two progress reports are required. Teams submitting reports considered to be below acceptable standards will be referred to a writing consultant in the UH Writing Center. After assistance and feedback from the writing consultant, these teams will be given the chance to resubmit their reports, although the highest grade it can receive will be a "C". These teams will also submit their second progress report directly to the writing consultant instead of to the instructor and after receiving feedback and rewriting as necessary, submit it to the instructor one week after the original deadline. Should this revised, second progress report be unacceptable, the team will submit its final report to the writing consultant for review and rewrite before submitting it to the instructor one week late.

These two progress reports, respectively, report on the work completed by the team and its members during the following time periods:

Progress Report #1: August 22nd thru September 25th
Progress Report #2: September 26th thru October 16th

Refer to the material presented and provided on the progress reports at the Writing Center Workshops for general instructions. In addition, consider the following requirements: Each progress report should describe the work completed since the last progress report, explain how the team is (or is not) following its plan (i.e., is it on schedule?), point out unexpected problems, comment on anything of interest or concern, and include a (revised) work plan for the remainder of the project. There should be evidence of work completed such as drawings and/or descriptions of concepts considered, photographs of prototypes, testing results, etc. Each team meeting should be documented, including attendance, time, place, a summary of the topics discussed, concluding remarks and a list of action items. (This information may be reported in a table (spreadsheet) in the Appendix. Remember to reference all items in the appendix.) The first progress report should include a preliminary work schedule for the entire project (when you plan to have what done), including all testing and reporting, and a work assignment scheme (who is doing what). The second report should comment on the progress relative to the most recent schedule, report on any deviations (and explain why), and present a revised schedule. The second progress report should include the first progress report in an appendix.

The progress report should be submitted with an appropriately designed and/or selected cover. A "binder" of some form should be considered so that each current report can be easily added to the previously submitted report(s). The first (cover) page of each report should, as a minimum, identify the report (e.g., Progress Report #1), the time period covered, the team, the class, the team members, and the date. Each report should be submitted with a letter of transmittal (The letter can be placed in front of the cover page in the binder, even though in reality it should be "attached" to the front of the binder.) Each report should contain (in addition to the cover page) a Table of Contents, a List of Figures and Tables, the body of the report (beginning with the abstract and ending with the conclusion), references and appendices. Pages should be numbered. The body of the report (between the Table of Contents [or List of Figures] and the References [if any] should be limited to six pages (double spaced New Times Roman or equivalent 12 Font) not counting figures or tables. There are no page limits for the Appendices. All figures and tables, including those in the appendix, should be titled, numbered and referenced in the body of the report.

Presentation and Submission of the Device for Evaluation

Each team will have up to fifteen minutes on Wednesday, November 16th during the normal studio time

- to demonstrate a "successful Final Testing" and
- to present a description of its "solution".

During the fifteen-minute Presentation the device should demonstrate a "successful Final Testing": properly place at least two golf balls in one of the secondary containers and at least two ping pong balls in the other in less than 30 seconds with a device weighing less than 5 pounds and occupying a volume that would fit inside a cube with the 30-inch edge before deployment. Immediately after the Presentations the devices will be submitted for evaluated for: selection of design concept, creativity of construction, attention getting quality, esthetics (craftsmanship), robustness, and description. (Devices that were not successfully demonstrated during the Presentation will suffer a significant penalty in the Evaluation.) At the conclusion of the Presentations, each team is responsible for transporting its device to a designated location for evaluation. Each team should leave with the device a written description of how the device operates, drawing special attention to the outstanding design features of the device. (The device needs to be "sold." This material is also appropriate for inclusion in the Final Report.) The devices should be left in "operating" condition so that the instructor can evaluated their operations. A detailed set of written operating instructions would be useful. Devices may be retrieved after noon on Monday, November 21st.

In the remainder of its fifteen-minute presentation, each team shall present an interesting description of its project. The Presentation should have an attention-getting beginning and a structured conclusion. Descriptions of noteworthy successes and failures in the design and construction processes are usually effective in holding the audience's attention. All team members are expected to participate equally in the presentation. Teams are expected to make a PowerPoint presentation. It is your responsibility to check the compatibility of your disc/computer, etc. with the room's computer/projector BEFORE November 16th. All members of the class are expected to be present for the entire class period and should be prepared to participate in discussions of the devices. (Note: When preparing your presentation, practice makes perfect!)

Final Report and Extended Abstract

The Final Report and the Extended Abstract are due by 5 PM Wednesday, November 9th. If the instructor is not available to accept your report, you should "log" it in with the Department receptionist. The Final Report should contain an abstract; a problem statement; specifications (technical, ergonomic, economic and esthetic); a discussion of how the specifications were satisfied (or not and why), a description of the final design; subsystem identification; at least three distinct concepts for satisfying the design requirements (These should be the concepts that you considered during your design process and should be represented clearly. An evaluation of each concept with a list of pros and cons with respect to your specifications should be included.); design selection rationale (not only at the concept level but also for the subsystem and component selections); design drawings and/or photographs; list of materials and cost; descriptions of the prototype development and testing results; results of the Initial Testing and Final Testing; the earlier submitted and returned progress reports; and anything else that you consider appropriate. The body of the report (between the Table of Contents [or the List of Figures] and the References [if any] should be limited to ten pages, not counting tables and figures. There are no page limits for the Appendices. Note that information related to schedules and team planning, as required in the progress report, does not appear in the Final Report. Use good judgment and the information in the Communications handout in preparing this report. This report should be an informative, attractive, interesting, and creative document!

The Extended Abstract consists of a single 8½ by 11 in. page with text on the front side and properly references (in the text) tables and figures (usually four or less) on the back. The document is similar in content to the "report abstract", but it is longer. It should contain more details and, of course, the references, figures, and tables that are not permitted in the "report abstract". Assume that the reader of your Extended Abstract will not have access to your Final Report. Place the Extended Abstract directly after the letter of transmittal.

GRADING

	points
Progress Reports (2 at 8 points each)	16
Initial Testing*	8
Final Testing**	24
Presentation	8
Design Evaluation***	20
Final Report and Extended Abstract	24

*A device that is successful in either of its first two attempts at the Initial Testing receives 8 points.
Devices successful in their third attempt receive 6 points; in their fourth attempt, 4 points.
Devices first successful between October 3rd and October 10th will receive 2 points.

** For the Final Testing, points awarded will be determined by the following formula:
Testing Points = Figure of Merit + Bonus Points
Figure of Merit is determined by Eqn. (1)
Bonus points will be awarded to the successful devices as follows:

- the largest values of G+P, 6 points
- next largest values: 4 points each

- next largest values: 2 points each
- the smallest values of N-G-P or μ or τ, 6 points each
- next smallest values: 4 points each
- next smallest values: 2 points each

The values of these parameters are taken as defined when used in Eqn. (1). In cases of ties the bonus points will be averaged. That is, if two devices successfully separate all ten balls, both devices receive 5 bonus points, and the devices with next lowest number split the 2 points remaining.

The points for "Final Testing" (of the 24 available) will be awarded on a linear scale proportional to the total Testing Points (defined above). That is, the device with the most Testing Points will receive 24 points out of 24 for "Testing". Their Testing Points will determine the upper end, with zero at the lower end, of a linear scale which will determine the fraction of the 24 points each team will receive. For example, a team whose Testing Points are 80% of the top team will receive 80% of 24 or 19.2 points.

*** Devices unsuccessfully demonstrated during the Presentation on November 16th will suffer a penalty as discussed in the Presentation Section.

Normally, each team member receives the team grade. However, as part of the final exam each team member shall complete a peer evaluation form (provided by the instructor) indicating his/her estimate of the extent to which other members of the team fulfilled his/her responsibilities for the project. Should the workload be determined to be significantly disproportionate, the instructor may talk to members of the team individually. The instructor will take these completed forms and statements into consideration when assigning each student's grade for the project.

COST

It is suggested that the total material cost should not exceed $100; however, there is no penalty for spending more. You should provide an itemized list of the materials, their sources and costs, in the Final Report. Cost estimates should be included for borrowed, donated, and/or other "free" items.

SOME FINAL COMMENTS

The "performance" of the design is evaluated only at the Final Test. The evaluation of the device as a design artifact takes place only after a demonstration that the device satisfies the minimum requirements at the Presentation. During this evaluation, however, consideration will be given to the device's performance during the Final Test as well as its current chances of being successful. There is, however, no requirement that the same device must be used for all the tests/evaluations.

Ideas and designs shall be original and construction shall be performed by team members. No pre-constructed assemblies are permitted in the design. Devices may change at any time, e.g., between the Initial Testing and Final Testing or between the Final Testing and the Presentation, since new ideas may emerge after seeing the solutions of others. "Ruggedness" is usually an important feature of most successful designs.

All rules are subject to interpretation by the instructor and may even be changed should circumstances merit such action.