TEAM BUILDING THROUGH EARLY DESIGN/BUILD OPPORTUNITIES FOR FRESHMAN ENGINEERING STUDENTS

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ABSTRACT

Teamwork is crucial to the success of any large engineering project. The Accreditation Board for Engineering and Technology (ABET) and employers have stressed the importance of incorporating teamwork skills within the engineering curriculum. At Virginia Polytechnic Institute and State University, this is being implemented using a series of *hands-on* and *early-design* projects during the freshman year. As part of the on-going implementation of these activities at Virginia Tech, we have recently introduced a series of design/build projects for freshman student teams that are centered on a standardized kit of tools and materials dubbed the "MacGyver box". This program has been piloted with approximately 300 students during the fall semester of 2001 and is to be fully implemented into the Virginia Tech freshman engineering class by fall of 2002. This initiative has been well received by students, and offers an engaging and instructive method to introduce students to design, engineering economy, and the dynamics of teamwork.

Teams of four students are issued a MacGyver box, briefly introduced to the design process, and assigned projects to complete throughout the semester. For each project the student teams are given design criteria, instructed to develop several design alternatives, and then to select and build their best design. Only the tools and materials contained in the teams' MacGyver box may be used for construction. The limited availability of materials provides specific design challenges to the students and allows a unique means of control for the instructor. Several project assignments are given over the course of the semester and no replacement parts are allowed.

This paper will discuss the development and implementation of the MacGyver box program from conception through implementation. Specific topics include the procurement of funding, the MacGyver box inventory, the projects themselves, and the scale-up of the pilot program. The paper will also address responses from students and lessons learned during program implementation.

Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition

Introduction

The successful engineer must appreciate the important role teamwork plays in the engineering design process. The Accreditation Board for Engineering and Technology (ABET) and industry employers have expressed the need for engineering graduates to be proficient at working in teams and have listed team skills as a desirable characteristic in educational and recruitment goals. At Virginia Tech, we have piloted a program in our Introduction to Engineering courses (EF 1015 and EF 1016) that engages teams of freshman engineering students in a series of design/build projects intended to build team skills, introduce the design process, and to help acclimate freshman engineering students to university life.

The centerpiece of this program is a toolbox containing basic tools and materials. One identical toolbox is issued to each student team. Teams of four students must design, build and test several devices throughout the semester and may use only the contents of their own toolbox to accomplish the task. The limited availability of materials and the necessity of creative problem solving are reminiscent of a popular television show, therefore the toolboxes have been dubbed the "MacGyver box". The nature of the assignments force the students to improvise and adapt, using the available resources to successfully complete the assignment. At the time of evaluation, student teams are required to demonstrate the function of their device and submit a brief technical report that gives an overview of their design and contains design sketches. To create an added air of pride and competition, each MacGyver assignment is assessed in an open competition between all teams. The unique designs and the excitement of competing with their fellow students make the evaluation event somewhat of a cross between "MacGyver" and a miniature "Junk Yard Wars". This approach to introducing engineering design results in an experience that the students find both engaging and educational.

MacGyver Learning Objectives

The concept of the MacGyver box can be extended to incorporate any number of specific learning objectives by changing the nature of the assignments and/or the contents of the box. However, several primary learning goals remain constant:

- Develop teamwork skills among the engineering student body that may be carried forward in their academic and professional careers.
- Help students to appreciate the value of input from peoples of different backgrounds and cultures.
- Introduce the design process including, brainstorming, sketching, and analysis of alternative designs.
- Allow students an opportunity to put their ideas into practice by building and testing their MacGyver devices.
- Merge the educational and social needs of freshman engineering students during a critical period of their college experience.
- Encourage students to take risks with their designs.

Previously at Virginia Tech, the engineering students first design project was a major team project assigned in EF 1016 that accounted for 25% of their grade in that course.

The MacGyver projects assigned in EF 1015 allow students to take risks with their designs and learn from their experiences with a less severe grade penalty assigned in the case of failure. It also seems reasonable to assume that this early design/build and teamwork experience will translate into students that are better equipped for the larger design projects assigned the following semester in EF 1016.

The MacGyver Concept

Each team is assigned a numbered MacGyver box. The box number becomes their team number and team members are required to exchange names, phone numbers, and email addresses when the team is formed. All boxes contain the same materials, but students are given an inventory list with their MacGyver box and are required to perform a complete inventory by the end of the first week. Missing or broken components will only be replaced within the first week. This forces students to immediately become familiar with the contents of their box, and eliminates the headache of constantly dolling out "missing parts" throughout the semester. The identical contents of each box forces a level playing field for the teams so that the tools or financial resources of any individual student or team become irrelevant to their designs.

It is important for students to become comfortable interacting with others as necessary, not just with the two or three fellow classmates whom they may already know. To this end, I prefer to assign teams rather than let students pick their own. This enables the instructor to assure that the teams reflect greater student diversity. Alternatively, teams may be randomly assigned or picked based upon certain experience factors such as computer skills, drafting experience, and proficiency with tools. Ultimately, each method of forming teams has pros and cons; therefore some teams will be more functional than others.

Within the first few class lessons, students are given a brief introduction to the design process. Our coverage of design is limited to brainstorming, research and development, analysis of alternative designs, sketching, and the written report. The teams are required to maintain meeting logs that include attendance, meeting minutes, and work assignments. Typically, about 10 days is given from the time the assignment is made until the due date, this forces a division of labor between team members in order to complete the assignment on time. It is important that the assignments be sufficiently complex to require a team effort to complete within the allotted time. Project grades for the teams are based upon the quality of their design concepts, sketches, technical write up, and the performance of the built device relative to the design criteria given.

Well-defined and measurable design criteria are an essential element of each MacGyver assignment. It is also important that the rules of the project be clearly stated and that a significant component of grading is based on some measurable performance parameter. The design criteria give students the information they need to analyze their alternative designs and refine their final design for optimal performance. For example, if a bridge building assignment is made, points may be awarded based on a specific performance factor such as length of span * load. This performance factor is weighted with other criteria such as quality of sketches/write-up, creativity, and aesthetics. It is important that students understand the relative weight of these grading elements when the assignment is made so that these trade offs may be duly considered during the design process. This demonstrates to students the series of trade-offs and compromises associated with every engineering design. Despite the common pool of materials and specified performance criteria, we have found the student designs to be wonderfully creative and unique.

The MacGyver projects have been extremely popular with the students despite the fact that it requires a significant portion of their out-of-class time. This enthusiasm is largely due to a sense of competition between teams. The performance metric of each teams' design is evaluated during a common-time competition event. During this competition every team has their MacGyver device tested and students have the opportunity to view the designs of other teams. Most students describe the evaluation event as the "best part" of the MacGyver projects. During the fall of 2001 we had about 75 teams (300 students) participating in the MacGyver pilot program and the assessment event lasted about 2.5 hours. The assessment sessions turned out to be an enjoyable social event for the engineering students, if somewhat exhausting for the faculty. The event spawned many engineering discussions concerning the pros and cons of various designs, and the competitive atmosphere has the effect of raising the bar of expectation when students see the effort and creativity of their fellow students.

The MacGyver Box

The contents of the MacGyver box are open to changes, additions, and upgrades, from semester to semester, but a few essentials are required. Basic tools such as hammer, screwdrivers and pliers are needed for building also, materials for construction such as wood, cloth, and plastic, fastening systems such as glue, nuts/bolts, nails, and duct tape, a means of motive force such as springs, rubber bands, and electric motors, as well as other items which may be required for particular projects or learning objectives. A list of the core items included in our MacGyver box is given below.

• 1 Tool kit	• 1 electric motor	• pvc pipe
• 4 Paint sticks	• 1 solar cell	• batteries
• Popsicle sticks	• Elmer's glue	• led
• Box of toothpicks	• Mouse trap	• 2 clothespins
• Small spring set	• Small screws	• 4 wooden pencils
• Small gears	• Small nuts, bolts, nails	• large plastic wheels
• Plastic ruler	• Mechanics wire	• 24 inches of string

<u>Tool kit</u>: Our tool kits contain a hammer, screwdrivers, pliers, tape measure, and crescent wrench. Many large hardware and retail stores sell such kits as do discount outlets such as Big Lots and Dollar stores.
<u>Paint sticks</u> can usually be obtained from a local hardware store for free.

Most of the other items can be easily obtained from retail outlets, electronics suppliers, and crafts stores, though a good bit of legwork is required. For large purchases we have found most suppliers willing to offer a reasonable discount. A complete list of our first MacGyver box inventory is given as attachment 1.

Of course, procurement of the above items requires funds. At Virginia Tech we are fortunate to have an active Student Engineers' Council (SEC) that generously funded the MacGyver box initiative with $15,000 in start-up money. Purchase of the toolboxes and initial supplies cost approximately $37 per unit. A total of 300 boxes are required for full implementation of the MacGyver box program into the freshman engineering course at Virginia Tech. This translates to an initial cost of around $11,100, leaving $3,900 for re-supply of the boxes as necessary.

The MacGyver boxes contain some items that are permanent and other items that are expendable. Students using the boxes must be given clear instructions concerning how the contents of the box may be used. Obviously, the toolbox and tools should be returned intact at the end of the semester. Electronic components such as the motor, resistors, batteries, and solar cell should also be returned, though these should be tested for proper operation prior to re-use. We have found that the student teams are typically conservative in the use of materials because no chance of re-supply is offered beyond the first week. At the end of each semester the boxes are returned and inventoried by a student teaching assistant (TA) who assists us with the administration of the program. A significant portion of the grade for the final MacGyver project is predicated upon the return of the box and tools in good condition.

Maintenance of the MacGyver boxes requires a standing inventory of parts and supplies. This requires not only purchase of these items, but the space to store them and the means to inventory and restock the boxes. The boxes themselves require the most space, but are in student hands during the semester. Items in the box such as paint sticks, cloth, clothespins, mouse trap, and the like are inventoried by the student TA and re-stocked as necessary prior to re-issue of the boxes.

In order to improve safety and reduce mess, some materials should not be used as part of the MacGyver box inventory; candles, razor blades, super glue, and anything in a tube are best avoided. It is our hope that the contents of the MacGyver boxes can be continuously added to and upgraded so that we may continue offering the students unique and challenging MacGyver projects in coming years.

The MacGyver Projects

Few students have a realistic idea of what is expected from them when they enter the engineering program at Virginia Tech. Therefore, it is important to design the MacGyver projects using clear objectives, and to create some type of measurable statistic associated with design performance. The projects themselves may be almost anything, a launcher, a car, a boat, scales, etc. Faculty and students have offered a wealth of ideas. A synopsis of three of our MacGyver project assignments is given below.

The MacGyver Bridge

Problem Statement

As a group you are to construct a bridge that has a minimum length of 18" and supports a minimum of 1 EF textbook at its center. There are no ground supports allowed other than a chair or table placed at either end. To receive additional points you may have a longer bridge and/or more textbooks up to a maximum of 40 points.

Constraints

1. With the exception of paper and pencil, the only materials you can use are those in your own MacGyver box.
2. Any broken or altered items may NOT be replaced (both for this project and throughout the semester).
3. You may use no more than 1 linear foot of 2" wide duct tape on this project.
4. Your design will be tested only once and at the length and with the number of books you declare PRIOR to testing.
5. You may pretest your design but be aware of #2 above.
6. A test will be considered successful if it supports the load for five seconds.
7. You may not discuss this with any students outside your group.
8. Do not permanently alter or destroy any tools.

General Criteria

Length of span, in inches * # of books supported, 40 points
Aesthetics and creativity, 20 points
Quality of alternative designs, 20 points
Quality of final design write-up, 20

The MacGyver Vehicle

Problem Statement

As a group you are to design and fabricate a vehicle that will travel along the floor to a target precisely 15' away and stop. The target will be a 6 in diameter bulls eye, with concentric circles worth lesser values. A bulls eye is worth 60 points

Constraints

1. The only materials you may use for building are those in your own toolkit.
2. Broken or altered items may NOT be replaced (both for this project and throughout the semester).
3. You will have only two opportunities to run your design.
4. All motive and braking power for the vehicle must be self contained (e.g. the vehicle may not be pushed, propelled, launched, or tethered)
5. You may not discuss this with any students outside your group.
6. Do not permanently alter or destroy any tools or the toolbox.
7. The entire vehicle must be placed behind the start line.
8. A position indicator must be placed on your vehicle prior to testing to be used in distance measurement.

General Criteria

Accuracy, 60 points
Aesthetics and creativity, 20 points
Quality of alternative designs and sketches, 10 points
Quality of final design write-up, 10 points

The MacGyver Launcher
(final project)

Problem Statement

As a group, you are to design and fabricate a device that will launch a ping-pong ball a distance ranging from 1 through 6 feet with reasonable accuracy. The accuracy of your device will be evaluated using a target that will be placed somewhere within the specified range. The target will be a standard 5 gallon bucket, and the distance in feet away from the launcher will be determined by the roll of a die.

Each team will be given one ping-pong ball and will be allowed to attempt as many baskets as possible in a 1 minute period. Each basket is worth 5 points.

You are also required to return your MacGyver box and tools in good condition at the time of launcher testing.

Constraints

1. The only materials you may use for building are those in your own toolkit.
2. Broken or altered items may NOT be replaced.
3. A standard die will be rolled to set the target distance.
4. The entire launcher must be placed behind the foul line.
5. The bucket will be placed flat on the floor and entirely behind the distance rolled.
6. The bucket has dimensions of: inner diameter (11.0 inches), height (14.5 inches)
7. You will have 1minute to shoot as many baskets as possible.
8. You may not discuss this with any students outside your group.
9. Do not permanently alter or destroy any tools or the toolbox.

Grading Criteria

Baskets, 5 points each
Aesthetics and creativity, 10 points
Quality of alternative designs and sketches, 10 points
Quality of final design write-up, 10 points
Return of MacGyver box and tools, 50 points

Each group is also given a grade sheet with each assignment. The grade sheet contains a breakdown in grading, an honor pledge, and serves as a cover sheet for the submitted reports. A sample grade sheet is given as attachment 2. The student reports are required to contain a brief write up, sketches, Bill of Materials, and concept sketches for several alternative designs. The student TA is responsible for grading all reports so that a common standard is employed.

We have conducted the MacGyver evaluation event in a large atrium in one of the engineering buildings on campus, and have found this serves as a perfect venue. The large open area allows easy viewing for spectators. Designs have been cheered and booed by the assembled crowd, and the pride and ingenuity exhibited by the students is an obvious motivating factor. Four faculty members and a couple of student volunteers can test, score, and collect reports for 80 groups in about 2.5 hours. This event is enjoyable and educational for the students, but a lot of work for the faculty. The key is to determine the logistics and crowd management to be used beforehand. We scheduled students to arrive for testing in half hour shifts, but found that most students came early and stayed after testing of their device in order to observe other teams in action. When enabled, the students can be quite creative, not all designs are variations on a single theme and extra points are awarded for thinking outside of the box.

Student Response to the MacGyver program

Students were asked to write a brief paper describing what they had learned about working in teams during the semester. Overwhelmingly, students were glad to have participated in the MacGyver projects. More importantly, students recognized the value of contributions made by fellow teammates and the importance of team skills. Numerous students added that they had become friends with people with whom they might never have interacted, but for the projects. Many students also stated that they had forged alliances that they plan to continue in the future. In short, the MacGyver projects helped to demonstrate to the students the unique challenges and creative nature of the engineering profession.

Conclusions and lessons learned

While the MacGyver projects required almost no class time, a significant investment of time, effort and money is required outside of the classroom. Having a motivated student TA to implement the program was essential for us. Having assistance in the MacGyver box logistics and in project evaluation was essential for a program of our size.

While the occasionally dysfunctional teams are inevitable, most students had a very positive experience and were excited by the air of creative competition that surrounds each MacGyver assignment.

The following suggestions are offered to improve team dynamics and ease project administration.

- Require each group maintain a meeting log.
- Require a group inventory of the MacGyver box and only offer replacement parts during the first week of classes.
- Project design criteria must be clear and should contain some performance metric as part of the project grade.
- Structure the complexity and time allowed for the projects to force a team effort.
- Hold a common time competition to assess the built devices.
- Work out the logistics of the evaluation event beforehand.
- Employ student TA's to help administer the program.

Attachment 1

MacGyver Box Inventory list (2001-2002)

Material	Supplier	Price, $	Number per unit	Number in McBox	McBox price
clothespins	Big Lots	0.99	10	2	0.99
pencils	Big Lots	0.49	20	4	0.45
washers	Home Depot	11.89	745	10	0.16
screws	Home Depot	12.97	500	10	0.26
saw	Home Depot	12.47	10	1	1.25
nuts	Home Depot	1.79	100	5	0.09
bolts	Home Depot	9.49	100	2	0.19
Tool Box	Lowes	7.25	1	1	7.25
tool kit	K-Mart	8.99	1	1	8.99
straws	K-Mart	1.99	200	10	0.10
toothpicks	K-Mart	0.69	250	250	0.69
duck tape	K-Mart	2.75	1	1	2.75
trash bags	K-Mart	5.99	230	2	0.05
glue	K-Mart	0.79	1	1	0.79
rubber bands	K-Mart	2.48	500	5	0.02
springs	Lowes	3.97	50	3	0.24
strap ties	Lowes	5.00	500	10	0.10
PVC pipe	Lowes	1.00	10	0.5	0.05
9V battery	Lowes	9.97	8	1	1.25
film canister	Michael's	0.49	1	1	0.49
string	Michael's	2.39	325	2	0.01
popsicle sticks	Michael's	3.00	100	15	0.45
construction paper	Michael's	2.99	200	4	0.06
Wooden Dowels	Michael's	0.39	3	1	0.13
paper clips	Office Max	4.47	1000	25	0.11
thumbtacks	Office Max	2.58	250	10	0.10
binder clips	Office Max	2.57	30	3	0.26
ruler	Office Max	0.59	1	1	0.59
mousetrap	Pitsco	6.30	10	1	0.63
wire	Pitsco	5.95	55	1	0.1 1
wheels	Pitsco	15.00	100	4	0.60
axles (2.5" steel)	Pitsco	3.00	100	5	0.15
axle retainers	Pitsco	6.95	100	6	0.42
gears (10 packs of 5)	Pitsco	2.50	10	1	0.25
LED light red	Pitsco	4.00	10	1	0.40
shipping	Pitsco	25.00	100	1	0.25
110 ohm resistors	Radio Shack	0.01	1	1	0.01
220 ohm resistors	Radio Shack	0.01	1	1	0.01
330 ohm resistors	Radio Shack	0.01	1	1	0.01
battery snap	Radio Shack	1.25	5	1	0.25
motor	Radio Shack	0.74	1	1	0.74
solar cell	Radio Shack	5.09	1	1	5.09
shipping	Radio Shack	32.00	100	1	0.32
SEC Sticker	TNT Signs	0.80	1	1	0.80
fabric	Wal-Mart	1.87	1	0.2	0.31

Total cost = $36.78 per box

Attachment 2

Instructor ________________ Group#_______ Section__________

My signature below verifies that I have participated in, and significantly contributed to, this project.

Print names (Last, First)	Signature
____________________________	____________________________
____________________________	____________________________
____________________________	____________________________
____________________________	____________________________

The MacGyver Vehicle

Grading

Function

Performance	___________	(0 to 60 max)
Aesthetics and creativity	___________	(0 to 20 max)

Alternatives

Quality of alternative ideas and sketches	___________	(0 to 10 max)
Final design write-up	___________	(0 to 10 max)
TOTAL	___________	(0 to 100 max)

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Katharine Davenport is currently a senior majoring in Chemical Engineering and Chemistry at Virginia Tech, in Blacksburg, VA. Upon graduation in May 2002, she plans to pursue a Master of Science in Environmental Engineering at Virginia Tech.