Abstract

In order to stimulate enthusiasm for engineering among its students, and to promote leadership, creativity, resourcefulness, critical thinking, and social consciousness of the impact of engineering, the School of Engineering and Applied Science (SEAS) at the University of Virginia (UVA) has undertaken a cluster of curricular enhancements called Engineering in Context (EIC). One aspect of this effort is an expanded first year design experience. This experience provides a structured approach to the design process, while allowing the students an opportunity to achieve a substantial and rewarding end product. The aim is to provide open-ended projects that develop students’ engineering skills and also allow them to see more directly the connections between engineering and the larger society around them. Collaborations with fine arts departments provide engineering students the opportunities to address social issues, while developing creativity and technical skills. This paper describes a collaboration with the Drama department to create special effects for student-written and directed plays.

Introduction

Engineering is fun. Well, at least it’s supposed to be. Unfortunately, many first-year engineering experiences are mostly work and not much play. The “Inside the Box” project is an attempt to provide a first-year design experience to engineering students at the University of Virginia that draws out student creativity, develops hands-on skills, and is fun.
The result was a three-class collaboration between students in Engineering and Drama. Their mission: to create 10-minute theatrical productions with student written, student directed, and student engineered plays. Rain, snow, cupid’s arrow whizzing across the stage, blowing leaves and falling rose petals, were just a few of the special effects developed by the first-year engineering students. The plays were performed on December 9 & 10, 2004 to a packed house both nights.

In ENGR 162 section 12, each team of 4 to 5 students was matched with a student playwright from the class DRAM 372, Introduction to Playwriting, and a student director from DRAM 351, Directing and Stage Management. The playwriting student composed a short play that incorporated three special effects. The directing students added two additional effects and cast and staged the plays. The action of the scene took place within and around a 10’cube called “the Grid”, to which engineering students attached their effects. Hence, “Inside the Box”

Engineering in Context

[Engineeering schools...are increasingly out of touch with the practice of engineering...Many of the students who make it to graduation enter the workforce ill-equipped for the complex interactions across many disciplines of real-world engineered systems...What’s needed is a major shift in engineering education’s center of gravity, which has moved not at all since the last shift, some 50 years ago, to the so-called ‘engineering science’ model...Engineering is creativity constrained by nature, by cost, by concerns of safety, environmental impact, ergonomics, reliability, manufacturability, maintainability...To be sure the realities of nature is one of the constraint sets we work under, but it is far from the only one, it is seldom the hardest one, and almost never the limiting one. — William A. Wulf and George M. C. Fisher, Issues in Science and Technology, Spring 2002.

The Accreditation Board for Engineering and Technology (ABET) has issued a call for rethinking engineering education with its Engineering Criteria (EC) 2000. No longer is it sufficient for programs to demonstrate that they provide students with the appropriate inputs: a specified minimum number of credits in fundamental math and science, engineering science, engineering design, and humanities and social science. Now programs must demonstrate the attainment of specified outputs: capabilities achieved by students in eleven different skill areas specified by ABET, as well as additional areas selected by the programs themselves.

The eleven skills specified by ABET in criterion three, together with the design requirement of criterion four, emphasize the interdisciplinary nature of 21st century engineering. Engineering graduates must be able to demonstrate competence in traditional engineering-related tasks such as:

a) apply knowledge of mathematics, science and engineering,
b) design and conduct experiments as well as analyze and interpret data,
c) design a system, component or process to meet desired needs,
d) identify, formulate, and solve engineering problems, and
k) use the techniques, skills and modern engineering tools necessary for engineering practice.

Engineering graduates must now also
d) be able to function on multidisciplinary teams,
f) understand "professional and ethical responsibility",
g) "communicate effectively",
i) "engage in life-long learning",
j) have "a knowledge of contemporary issues", and
h) have "the broad education necessary to understand the impact of engineering solutions in a global and societal context."

The School of Engineering and Applied Science at the University of Virginia has a long history of emphasis on these “contextual” outcomes as exemplified by our Department of Science, Technology, and Society, and an undergraduate thesis required of all students. The Engineering in Context initiative seeks to further infuse engagement with context throughout the engineering curriculum.

**Design as a Vehicle for Context**

Although much more can be done to integrate context into normal engineering lecture classes, the full realization of the EIC 2000 revolution can best be achieved in multidisciplinary student design projects. Important as each is in its own right, if the skills of criterion three are pursued in isolation, in separate courses, taught by faculty with little or no communication with one another, little will have been achieved. Only by integrating these aspects in concrete open-ended problems (through which instructors patiently but not too directly guide students) that we can claim to be developing such qualities as initiative, resourcefulness, creativity, and leadership desired in an engineering graduate. Pioneering work in this area has been performed at Lehigh University [Ochs, 2004], Rensselaer Polytechnic Institute [Gabriele, 2004], the University of Virginia [Neeley, 2004], and elsewhere. Most of these efforts have been focused on capstone courses for upper class students.

**Integrating Context into First-Year Design**

The primary goal of ENGR 162 is to introduce students to the fun and challenge of real world engineering practice through multidisciplinary design experiences and realistic, open-ended problem solving. The course seeks to develop an appreciation for the importance of the context (social, cultural, economic, environmental, organizational, regulatory…) in which the technical work of engineers is accomplished. It also stresses the importance of oral and written communications skills, multidisciplinary teamwork, and creativity in engineering. Emphasis is on a balanced perspective incorporating contextual (non-technical) factors, which are sometimes more critical than analytical skills in determining the success of the modern engineer.

Educational Research has demonstrated the importance of seeing the big picture for effective learning. Students learn best when they can integrate new material into a preexisting context of understanding. The literature review of *How People Learn*, published by the National Academies Press (Commission, 2000) reported the success of a ‘metacognitive’ approach in which students “monitored their own understanding carefully, making note of when additional information was required for
understanding, whether new information was consistent with what they already knew, and what analogies could be drawn that would advance their understanding." (Ibid, p. 18) Engineering education has tended to consist of discreet packages of narrowly focused material and has paid little attention to the need for an integrating framework to enhance learning of that material. It is our hope that realistic engineering design projects at the outset of students’ engineering studies will provide a “metacognitive” framework that will enhance their learning throughout the rest of their curricula.

By increasing the time devoted to realistic, socially-meaningful engineering problems in the first-year, we expect our students to develop an earlier commitment to their profession. Some studies suggest that this emphasis may also attract and retain larger numbers of minorities and women to the engineering profession. Sue Rosser, author of Female Friendly Science, contends that “if students study engineering in its social context, solve more real-world problems, and learn interdisciplinary approaches to the field, it could have a strong impact [on female enrollments in engineering]” [Rosser, 2001]. By involving students in team projects which require active and collaborative synthesis and decision-making and which provide a real-world context to which students can connect, we expect to foster engagement and improve learning effectiveness in our students.

ENGR 162 design workshops have addressed such problems as emergency shelters for the homeless, handicap access, wildfire suppression, the transportation needs of Charlottesville, VA, and improving service in one of the most used lunch facilities on campus. One of the authors of this paper developed a project that engaged engineering students to work with UVA Facilities Management in auditing energy use of campus buildings and designing energy retrofits. Many of these designs have been implemented resulting in thousands of dollars of energy savings. These collaborations resulted in awards from the Environmental Protection Agency of Greenlights Partner of the Year in 1999 and Energy Star Partner of the Year in 2001. [Marshall, 1999]

Expanding students’ perspectives beyond the confines of traditional disciplinary boundaries enhances students' abilities to contribute as citizens in utilizing technology to achieve broader social ends. The activities bring humanistic concerns such as ethics, values, and social justice to bear on technological decision-making, while helping students to incorporate technology into their world-view as a powerful, yet constrained, tool for achieving human ends. They will also be better prepared to assume leadership in advancing the corporate and economic goals of the enterprises they join after graduation.

**Engineering and the Arts**

Engineering education has lost touch with engineering practice, in part by emphasizing science over art. Analytic skills have been given precedence over creativity. One of the authors of this paper has attempted to restore this balance by engaging students in interdisciplinary projects with students in architecture, and has advocated the architecture studio as a model for engineering design projects. [Snyder, 2001, Marshall, 2002, 2003a, 2003b, 2004] The current project continues the effort to expand the creative horizons of engineering students by engaging them in projects with students from the arts.
Inside the Box Background

The idea for “Inside the Box” was born when Professor Marshall asked teaching assistant Benjamin Kidd to come up with a semester long design project for Marshall’s section of Introduction to Engineering workshop. “Preferably something that you enjoy and find interesting,” Marshall said. Special effects had crossed Benjamin’s mind on several occasions, but it was not until speaking with the stage lighting professor Lee Kennedy at the drama department that a true idea began to take shape.

During their conversation Benjamin got the idea for the “Grid.” The cubic structure, ten feet on every side was used to provide a basis for the engineers’ work. The design for this structure evolved alongside the idea of using theatrical special effects as the central theme for the project. The idea to actively involve the drama department was the next step. “We could have playwrights create original plays and define the special effects,” Benjamin suggested to Lee Kennedy. Professor Kennedy sold the idea to the playwriting professor, Doug Grissom, and also mentioned it to the Directing professor, Betsy Tucker. Tucker liked the idea so much she made it the final project for her stage management and directing class.

The Special Effects

A collaborative process then began which resulted in a project description document containing the project rules and goals, 3D renderings of the grid structure, and specifications regarding safety. One of the first and most important decisions was to standardize the number and types of effects that would be incorporated into each play. Five effects were chosen for variety and technical difficulty. The following list provides detail and description of each effect.

1. **Balloon popping**
   *This effect is purposely left open-ended. The balloon popping may be an effect unto itself, or a means of accomplishing another purpose.*

2. **Falling objects**
   *Objects must fall for a duration of not-less-than five (5) seconds. Falling items are subject to approval for safety purposes.*
   Examples of objects that might fall:
   a. Feathers
   b. Paper
   c. Leaves
   d. Ping-Pong balls
   e. Rice

3. **Light moving across an actors face**
   *This effect is also purposely vague. A light, however, must be seen to be moving across an actors face, either side to side, up or down, or some combination thereof.*

4. **A flying effect**
   *An object or objects must fly though all or part of the acting space. Movement
must be predominately horizontal, in contrast to effect number 2, which is predominately vertical. Flying objects are subject to approval for safety purposes.

5. **A weather effect**

Create one of the following weather conditions. Weather conditions not listed shall be acceptable upon approval.

- Rain
- Snowfall
- Fog
- Thunder Storm

The interpretation of these effects in the context of each play was left to the playwright, and the director for each team of students.

Each of these effects was to be controlled remotely by the engineering students through electrical, mechanical, pneumatic, or some other means. Effects had to be remotely controlled from at least 20’ from the front of the “Grid”. To add to the challenge and keep the final performance time efficient, the engineers had to be able to setup their effects in five minutes or less. This setup time included anything that had to be mounted to the grid structure. Similarly, all items had to be removed from the structure and surrounding area in five minutes. This constraint forced designs to be portable and their setup to be pre-planned and rehearsed, simulating the real time-constrained nature of technical theater. Amazingly, all of the groups completed their setup and take-down within the five minute time limit.

**Structuring the Teams**

The students were divided into nine teams (nine playwriting students from Doug Grissom’s class participated in the project.) Accordingly, each group was assigned four to five engineering students from the ENGR-162 class (40 students total), and a director and stage manager from the directing and stage management class. The engineering teams were formed by Marshall and Kidd, using a self-evaluation of leadership, technical, and theater experiences, which the engineering students completed during the first week of classes. An attempt was made to create teams with strengths in all three areas.

**Inside the Project**

The following section provides an overview of the topical, technical, and financial resources that were used in the project.

**Technical Lectures**

Preparing the engineering students with the technical knowledge necessary to design and build working prototypes of their effects was no small feat. Technical material was researched and presented including several demonstrations during each lecture, accompanied occasionally by hands-on activities. The following chart shows the topics in the order that they were presented. Many of the Power Point Presentations are available at [www.seas.virginia.edu/academic/insidethebox/](http://www.seas.virginia.edu/academic/insidethebox/)
<table>
<thead>
<tr>
<th>No.</th>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic Electricity</td>
<td>Introduction to basic electrical and circuit theory, the difference between AC and DC.</td>
</tr>
<tr>
<td>2</td>
<td>Circuit Control</td>
<td>Using circuit breakers and fuses to protect circuits. Using switches to control circuits.</td>
</tr>
<tr>
<td>3</td>
<td>Electromagnetism</td>
<td>Understanding and using electromagnets, solenoids, relays, and transformers.</td>
</tr>
<tr>
<td>4</td>
<td>Team Building</td>
<td>Review of basic electrical topics and then a special paper tower building contest to practice teamwork and leadership skills between engineering students.</td>
</tr>
<tr>
<td>5</td>
<td>Basic Mechanics</td>
<td>Introduction to the notion of torque, rotational energy, gear ratios, work reduction, chain/pulley drive systems, and mechanical advantage.</td>
</tr>
<tr>
<td>6</td>
<td>Pneumatics</td>
<td>Introduction to pneumatic concepts, terminology, and devices, including valves, pneumatic cylinders, flow, and pressure.</td>
</tr>
<tr>
<td>7</td>
<td>Soldering and example Gearbox</td>
<td>This lecture included step-by-step instructions for soldering, as well as instructions and a demonstration of a simple gearbox used as a winch for raising and lowering a small prop.</td>
</tr>
<tr>
<td>8</td>
<td>Various</td>
<td>This lecture included a review of a variety of topics including pneumatic connectors, solenoid valves for air and water, an explanation of the DPDT reversing circuit.</td>
</tr>
<tr>
<td>9</td>
<td>Stage Lighting</td>
<td>Professor Lee Kennedy of the drama department along with Benjamin Kidd talked about the history of stage lighting, optics, current lighting equipment, systems, and basic control architectures.</td>
</tr>
<tr>
<td>10</td>
<td>Lamps</td>
<td>Focused on readily available lamps, such as A, R, PAR, and MR-16 style lamps and their beam patterns.</td>
</tr>
<tr>
<td>11</td>
<td>Electrical Connectors</td>
<td>A survey of available electrical connectors such as Molex, Cinch Jones, RJ-11/12/45, and their relative advantages and disadvantages.</td>
</tr>
</tbody>
</table>

**The Grid**

In order to facilitate development of the special effects and to provide a base-line infrastructure for the students, the “Grid” system was implemented, shown in figure 1. This system consists of a 10’ by 10’ by 10’ cube made from 1” electro-metallic (EMT) conduit. Each of the four vertical conduits is supported by standard PA speaker stands. Electrical power in the form of 12VDC and 120VAC were provided from receptacle mounted on each of the vertical conduits. Students could hang, mount, or otherwise attach their special-effect producing devices to this grid system, or in a defined area around the structure called the “Acting Space.”
**Acting Space**

The “acting space” was the physical space inside and around the grid designated for the primary theatrical action. It was restricted to a 5’ perimeter on three sides of the grid-structure. In particular, the special effects had to take place within this perimeter, without being touched or controlled by the actors or engineers. A 20’ minimum control distance was established, requiring the engineers to be able to activate all of their effects remotely. The following diagram shows an overhead view of the acting space.
Budget for the Project

Costs often constrain what can be achieved in “real-world” engineering projects. To introduce budgetary considerations to the design, groups were allotted $100 to pay for supplies for their project, and allowed an additional expenditure of no more than $50 in personal funds. They were allowed to use any supplies that they had on hand or could scrounge from available “junk” boxes.

Funding for the project was provided by the School of Engineering and Applied Science, the College of Arts and Sciences and the Office of the Provost. The following chart is a summary of expenditures for the “Inside the Box” project.

<table>
<thead>
<tr>
<th>Cost</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$625.16</td>
<td>Grid – All costs associated with building the grid including electrical and structural.</td>
</tr>
<tr>
<td>$1,242.12</td>
<td>Parts ordered for students including switches, relays, solenoids, motors, lumber, tubing, PVC pipe, etc.</td>
</tr>
<tr>
<td>$132.55</td>
<td>Miscellaneous costs</td>
</tr>
<tr>
<td>$139.79</td>
<td>Soldering Stations custom designed and built that included stable stands and on/off switches, and a small tool kit.</td>
</tr>
<tr>
<td>$29.18</td>
<td>Paper Tower Building Contest</td>
</tr>
<tr>
<td>$24.48</td>
<td>Electrical teaching activity which involved letting students create a simple flashlight circuit with a battery and flashlight lamp</td>
</tr>
</tbody>
</table>
Design Methodology and Context:

Technical instruction was integrated into an introduction to a structured design methodology using the text *Engineering Design* by Dym and Little [Dym, 2004]. Teams engaged in exercises addressing problem definition, establishing objectives and user-requirements, identifying constraints, establishing design functions and specifications, generating design alternatives, preliminary design and test, final design, documentation, and design presentation. Final reports and presentations are available online at: www.seas.virginia.edu/academic/insidethebox/

Class discussion topics included: adjusting to college, the engineering profession and disciplines, team dynamics and communication, case studies in engineering ethics, the time-value of money, safety and environmental considerations in design, and customer relations. Team building exercises and discussions were held throughout the semester. Students developed a first-hand appreciation for the critical importance of timely and accurate communication among team members, and between the team and the clients.

The Client Connection

One of the greatest challenges of introductory engineering design courses is to provide or simulate the client/designer/user relationship. This project explores that relationship in a very real way. Thanks to the collaborative effort of the Drama department, students have real clients with real (though often ill-defined) needs. They face constraints very similar to those found in professional engineering environments (small budget, short amount of time to complete the project, limited resources) and even overall regulatory specifications that they must meet for safety and competition. To be successful the engineers had to understand their playwright and director clients’ visions of how the effects must integrate with the script and the acting to communicate the message and mood sought by the dramatists. As in a real world project, the engineers had to learn how to effectively contribute their creative ideas to help their client understand and specify their own objectives. They also had to communicate clearly to their clients the technical and material considerations that constrain the realization of the client’s goals.

Conclusion

The projects concluded at the end of the semester with a performance of the plays, including the special effects. The plays were performed over two nights to packed houses and appreciative audiences. Over ninety percent of the effects performed as intended, and a number of them drew accolades from the audience and reviewers. Students with little or no technical experience learned to hammer, saw, screw, wire, and solder. They selected and operated switches, relays, solenoids, gears, and motors. Their
designs exhibited initiative, ingenuity, and creativity. They developed teaming skills and learned to appreciate the importance of clear communication within the team and with the client. They explored the messages of the plays and the moods and reactions of the characters in order to enhance them with the effects. They learned that engineering requires human skills and an appreciation of context, along with technical skills. Importantly, they learned that a successful engineering outcome requires initiative, resourcefulness, and judgment, qualities that are too little emphasized in traditional analysis-based courses. They learned to appreciate that engineering is art as well as science. And they had great fun!!

In addition it is our belief and hope that an integrative design experience at the outset of the students’ academic study of engineering will provide a ‘metacognitive’ framework (Commission, 2000) that will add perspective to the more narrowly focused analytical courses that make up the bulk of the curriculum, and that the framework, as it becomes increasingly fleshed out by experience, will form the basis for a lifetime of engineering learning.

Bibliography:


Gary Gabriele, “Product Design and Innovation Curriculum”, ASEE Annual Conference, June 2004


Paxton Marshall, Dan Pearce, David Click, “Bridging the Engineering/Architecture Divide: The UVA Solar Decathlon Team”, ASEE Annual Conference, June 2003


Authors’ Biographies

**Paxton Marshall** is Professor in the Charles L. Brown Department of Electrical and Computer Engineering and Associate Dean for Undergraduate Programs in the School of Engineering and Applied Science at the University of Virginia. A former chair of the Energy Conversion and Conservation and Engineering and Public Policy Divisions of ASEE, Marshall has been involved in a variety of activities to develop design projects that integrate engineering with the liberal and fine arts.

**Benjamin Kidd** is a graduate student in the Charles L. Brown Department of Electrical and Computer Engineering at the University of Virginia. He holds a B.S. in Electrical Engineering, also from the University of Virginia, where his research included stage lighting systems and outdoor display pyrotechnics control systems. Benjamin's interests include Amateur “Ham” Radio (Callsign KG4EIF), stage lighting, pyrotechnics, Boy Scouts, electricity education, model railroading, and Jazz Performance.