Engineering Problem Solving Design Project: Emergency/Homeless Shelter Design

Julie L. P. Jessop, Tonya L. Peeples
The University of Iowa

Abstract

The Emergency/Homeless Shelter Design Project was developed for "Engineering Problem Solving I", a freshman engineering course, based on an exercise presented in *Engineering Your Future: A Project-Based Introduction to Engineering*. The purpose of the project is to encourage students to apply their design skills to serve society. Students are challenged to design a cardboard structure to keep people warm in cold weather, which will be warmed with sunlight and body heat. Classroom activities that help the teams in studying the issues of housing design include a guest lecture by the CEO of PEER Consultants, P.C. (an international civil and environmental engineering consultancy), brainstorming sessions to generate ideas for the design, a virtual building assignment using *Energy-10* software to evaluate the energy efficiency of a variety of building materials, and lectures on oral and written communications of technical material. Teams of four first-year students write a proposal for the design of a low-cost shelter and then build and test a prototype of the structure using a basic kit provided to them. The designs are demonstrated during the final week of classes in a poster session where students, faculty and staff are invited to view the shelters and technical posters describing the designs and testing results.

Course History

The current version of "Engineering Problem Solving I" (EPSI) was first delivered three years ago and is a required core course for incoming College of Engineering students.[1] This 3-credit course consists both of a lecture and a faculty-directed project component, each having equal student contact (1.5 hours). The lecture meets twice weekly with each of the four 100-student sections for 11 weeks (22 meetings). One faculty member is responsible for the lecture component of the course. Twelve project sections each meet over the course of the entire semester. Six faculty members are assigned two coordinated sections. Each single 32-student section can meet individually for one hour per week, as well as an additional hour jointly with the other section taught by the same instructor.

The general philosophy of this course is to use it as a vehicle to introduce the student to a structured engineering design problem-solving paradigm and common elements. As such, one objective is to provide students with a "road map" on how engineers typically go about solving problems, an idea of what specific skills may be important and why, and a realization of what typically characterizes and differentiates engineering from other disciplines. Lecture problems focus on application of skills by individual students as applied to problem "analysis", skills typically incorporated in one or more of the design process steps. Topics covered in the lecture sections include graphical representation of data, problem solving, design paradigms, sustainability, engineering economics, and life-cycle assessment.

In the companion project sections, the students work in small groups of 3-5 students. This component of the course is not designed to be a "lab" for the lecture section, but an independent section having activities that are coordinated around the overall design process steps adapted from the text used in the lecture.[3] Included is a requirement for oral and written reports. Projects are selected by the faculty and are appropriate for freshman students of diverse and limited background. They also do not rely on overly specialized skills, but utilize common elements of problem solving. Effective use is made of the students' innate problem-solving skills and "street smarts" in creative problem solving.

Introduction

We have been team-teaching two EPSI project sections together for the past two years. Evaluation of the lecture and lab sections from previous years was based on instructor and student assessment as well as on student performance on course learning goals. Table 1 shows student comments about the design projects from 2003.

Table 1. Student Feedback on EPSI Design Projects for Fall 2003.

"Didn't go with lecture enough"
"I would have enjoyed doing a more "physical" project. This is why I enjoyed the straw tower project; it was physically building and designing."
"We didn't have enough hands-on design and building projects."
"Could have more projects that required us to make something."
"Project didn't tie into lecture."
"Projects didn't include design as much as I'd have liked."
"[I would have liked more] relevancy/importance/appeal factors of projects"

In general, students expressed a desire for more building projects and more of a connection between design projects and lecture material. Based on feedback from last year's sections, we wanted to develop a new final project that would be more hands-on for the teams, yet would enable them to use the entire design loop (*i.e.*, Identify Need – Communication).[3] Keeping all other projects the same, we adapted and expanded the Emergency/Homeless Shelter Design Project for EPSI from an exercise presented in *Engineering Your Future: A Project-Based Introduction to Engineering*[4] to replace the final design project in 2004. This was an especially compelling exercise because homelessness is a current issue in Iowa City and has gained front-page coverage in the local newspapers.[5-8] Students could see how their engineering project results could be extended to address immediate societal needs. Thus, this project supports a broader goal of the educational mandate in the University of Iowa College of Engineering (UI CoE) as expressed by the Accreditation Board for Engineering and Technology (ABET): "Each graduate will have an education that is supportive of a broad awareness of the diversity of the world and its cultures, and that provides an understanding of the impact of engineering practice in the global/societal context."[9] This paper provides an overview of the lectures, materials and activities that comprise the Emergency/Homeless Shelter Design Project that we give our students as a capstone design project in our EPSI project sections.

Project Timeline and Deliverables

The purpose of the Emergency/Homeless Shelter Design Project is to encourage students to apply their design skills to serve society. In the homeless shelter design project, students are challenged to design a structure to keep people warm in cold weather using sunlight and body heat. Through this project, first-year engineering students investigate sustainable design, heating ventilation and air conditioning principles, local thermal patterns, and heat-transfer issues related to human comfort and survival.

Teams of three or four students were given six weeks (see Table 2) to respond to a request for proposal (RFP) that considered eight design constraints. These teams had been working together for nine weeks prior to the assignment and had completed three mini-projects and three large projects. Most teams were in the "performing" stage of team development.[10]

Table 2. Course timeline for Shelter Project.

Project Activity	(Due) Date
Introduction of Project Sustainable Design Guest Lecture	Week 1
First Progress Report	Beginning of Week 3
Virtual Building Assignment	End of Week 3
Second Progress Report	Middle of Week 4
Shelter Proposal	End of Week 5
Shelter Demonstration Poster Presentation	End of Week 6
Team Assessment	End of Week 6

The project was introduced in class with a lecture on proposal writing and with handouts containing the problem statement, the RFP, and the virtual building assignment. The same week, Dr. Lilia Abron, CEO of PEER Consultants, P.C.,[11] led an in-class brainstorming session to help the students begin defining the problem and searching for possible solutions (Steps 2 and 3 in the engineering design process[3]). The next two weeks were spent learning to use *Energy-10*,[12] a building simulation software package, which would provide guidance for their choice of building materials and energy strategies. Teams spent the remaining three weeks developing a design, writing the proposal, constructing the cardboard prototype, and making a poster for the final presentation. At the end of the six-week period, all 16 EPSI teams had produced the following deliverables:

- An evaluation of building design modifications for energy efficiency
- A project proposal for the design of an emergency/homeless shelter
- Pictogram instructions to enable an independent user to assemble the shelter
- A cardboard prototype demonstrating the shelter design and assembly
- A poster describing the design process and sustainable design features of the shelter
- An assessment of each team member's contribution to the overall group effort.

Shelter Proposal

We stress written communication throughout our EPSI project sections. Before the Emergency/Homeless Shelter Design Project is introduced, the teams have had practice writing memos, activity reports, and project reports. During the Shelter Design Project, the proposal is the mode of written communication the teams use to convey their results. The first lecture prepares them for this by covering the components and contents of the proposal that we require:

- Letter of Transmittal
- Cover Sheet
- Executive Summary (no more than 500 words)
- Introduction and Background (no more than 1 page)
- Project Description (no more than 3 pages)
- Timeline and Milestones
- References Cited
- Budget
- Qualifications (a 1-page resume for each team member)

Students are also directed to additional resources, such as the UI CoE Hanson Center for Technical Communication[13] and web pages providing more detail for student proposal writing,[14,15] to improve their final written product.

When the Emergency/Homeless Shelter Design Project is introduced to the class, we encourage the students to address the situation of overcrowded shelters. The 16 engineering teams are challenged to design an emergency shelter that would enable a homeless family to survive for a few days during the winter until suitable housing could be found. The rules for the shelter development are listed in a one-page RFP (see Table 3), a common method used by companies, the government and other agencies to outline their needs for projects. The eight shelter design constraints are among those listed in the exercise presented in *Engineering Your Future: A Project-Based Introduction to Engineering*.[4] Proposals are reviewed by the course instructors, and teams are given feedback to make sure that the designs are consistent with the scope of the demonstration goals.

Table 3. Excerpt from the RFP presented to EPSI design teams.

Project Description: Design a low-cost structure that will allow people to survive outside during cold weather. Structures which demonstrate sustainable design will be considered favorably. The shelter design constraints are as follows: 1. Shelter Capacity: Protect four people for a period of up to three days. 2. Construction Materials: Prototype—Standard 3/16" corrugated cardboard, plus any additional materials for insulation, waterproofing, and protection. Other hardware as required for fastening, anchoring, packaging, *etc*. No more than $50.00 in additional expenses per team.

3. To minimize cost of an individual shelter, the shelter must have an external surface area of 120 square feet or less. The thickness of the wall should not exceed 5 inches.
4. The human-generated heat is retained, and most heat does not escape the shelter.
5. The shelter must provide proper ventilation such that enough air is circulating that will allow four people to breathe.
6. The shelter when empty must be held down to the ground so it does not blow away with gusts of wind up to 25 miles per hour.
7. The shelter must be assembled in fewer than 15 minutes and without any tools.
8. The instructions for the shelter must be in pictograms or cartoon format, so language or literacy is not a problem.

Sustainable Design Guest Lecture

We invited Dr. Lilia Abron to give a guest lecture early in the project timeline. She helped jumpstart the students' design efforts by discussing the global application of her engineering skills and by leading a brainstorming session for our EPSI students. She challenged the students' preconceived ideas of and prejudices against the homeless by reminding them that they could easily be in such a predicament due to natural disaster (*e.g.*, she was homeless for a time after the recent hurricanes filled her Florida condominium with several inches of water). Students who thought that a cardboard box was sufficient for the homeless began to reconsider their design criteria as she instructed them to design for themselves (*i.e.*, would they be able to ***live***—eat, sleep, bathe, *etc*.—in their shelter design?). She discussed various sustainable building materials, such as wood-wool cement boards,[16] and energy efficient strategies, such as passive solar technology,[17] and how they could be incorporated in their shelter designs. This reinforced topics covered in the EPSI lecture sections on sustainability. She ended with a PowerPoint presentation showing shanty towns in South Africa and the sustainable housing developments she and her company are creating in their stead.

Virtual Building Assignment

Since many engineers use simulation packages to design processes, plants, and pieces of equipment, we introduced our EPSI students to one of these tools during the Emergency/Homeless Shelter Design Project. In this project, we wanted them to gain an appreciation for adequate materials for their shelter by completing a sustainable design assignment using the *Energy-10* software. For the purpose of researching ideas, they were also instructed to visit internet sites regarding building design such as the Oak Ridge Building Institute[18] and the National Renewable Energy Laboratory building site.[12] Teams evaluated the energy efficiency of their designs using concepts learned from this virtual building project.

The virtual building assignment includes the first two tutorial exercises found in the *Energy-10* "Help" section and a "new lodging project." Exercises #1 (Sample) and #2 (Insulation) encourage the students to tour *Energy-10* and to become accustomed to viewing and manipulating the program input parameters. Exercise #3, the "new lodging project," is an open-ended design that enables the teams to study Energy-Efficiency Strategies (EES) for insulating materials. Each team submitted a summary including:

- A ranking of EES for the lodging structure based on the Net Present Value (NPV)
- A plot of R-value of wall insulation versus building cost
- The cost coefficient from the R-value versus building cost plot
- A plot of R-value of wall insulation versus energy savings
- A comparison of the reference case for the lodging structure insulation and the best low energy case.

From this exercise, students were able to visualize an optimal choice for insulation material and which EES would make the most sense for their shelter design. In addition, students were able to see a real-world application of the engineering economics evaluations they had been performing in the lecture portion of the course.

Shelter Design and Testing

Each EPSI team built a prototype of the structure (of 90% cardboard) to demonstrate the utility of their design and the ease of use of the pictogram instructions, all of which were presented in their proposals. A set of materials for shelter construction was given to each team (see Table 4). Teams were permitted to add to the basic kit to enhance their designs at their own expense, but were not allowed to spend more than $50.

Table 4. Shelter kit contents and cost.

12 ~ 3'×4' cardboard sheets	$6.00
1 roll of duct tape, 2"×50'	$4.00
1 roll of twine, 200'	$4.00
1 permanent marker	$1.00
1 poster display board	$5.00
TOTAL KIT COST (per team)	**$20.00**

Teams evaluated the energy efficiency of their designs using concepts learned from the virtual building project and efficient housing design brainstorming sessions. Teams also evaluated the cost of the temporary structure with pricing information on potential materials of construction from local building supply stores and the Internet. The full-scale designs were demonstrated during the final week of classes in a session where students, faculty and staff were invited to view the shelters and technical posters describing the designs and testing results.

Project Evaluation

The emergency/homeless shelters designed by our EPSI teams were impressive (see Figure 1). Each team had a unique design, and many teams added extra touches (*e.g.*, a sliding lock on the door, partitions in the structure for privacy, and a strawberry-scented air freshener). During the Shelter Demonstration, we mixed the teams up and had them erect each other's shelters using only the provided pictograms. All shelters easily met the "15-minute with no tools" assembly rule, and all could hold four people (some more comfortably than others!). Table 5 lists some of the student comments on the end-of-term project assessment.

Table 5. Student Feedback on EPSI Design Projects for Fall 2004.

"You got to put the things you learned in lecture to use."
"Last project culminated everything we covered all year (good end)."
"[One of the best aspects of the project section was] coming up with ideas and building things."
"[This class provided] an opportunity to encounter real-world problems and the difficulties engineers face."
"It let me use my problem-solving skills in a meaningful way."
"I felt I was accomplishing a goal and solving a problem during the shelter project."
"Keep the shelter project. I liked that."

Student feedback indicated that they enjoyed the hands-on activity and the opportunity to express their creativity. They also noted that they used all steps in the design loop (and even had to iterate some of the steps) during this final project. Each of the design elements was assessed based on a binary scale (1 meaning that the step was used or 0 that the step was not used). For the shelter project, all of the design steps were rated above 0.95 with S.D. below 0.15 (n = 62). This is an improvement over the final project for 2003, where all of the design elements were only rated above 0.85 with S.D. below 0.35 (n = 63). Students believed that the project activities required for the Shelter Design Project contributed to their learning as assessed on a six point scale (1 = agree strongly, 6 = disagree strongly), by rating it the highest of all projects with a score of 1.44 ± 1.01 (n = 62). When asked the same question in 2003, students gave the 2003 final project a rating of 2.75 ± 1.49 (n = 63). Thus, we were successful in developing a final project that addressed the concerns expressed by students from the previous year and met our objectives for a capstone project in the project section.

Figure 1. Examples of shelter prototypes designed and built by EPSI teams.

The biggest student frustrations during the Shelter Design Project were with the *Energy-10* software. This was no surprise since we were learning right along with them. In the next offering, we will have these glitches worked out so that the process of learning the software and using it in the exercises will be less painful. We will also have the software available on the engineering computer network so that the teams will have access to it at all times, rather than just in the computer labs during class time and office hours. Once the software is accessible to all

Engineering faculty, the EPSI lecture instructors could use it for life-cycle assessment exercises in the lecture portion of the course. Finally, some teams did not use the lessons learned from the software in their design, so the link between the virtual building assignment and the shelter design will be further emphasized in the future.

The team proposals addressed all required areas adequately; however, more explanation of timelines and milestones will be needed next time since several teams reported their activities during the six weeks in this section (rather than outlining what they would do in the future if funded). As the teams wrote the proposals, many found out that several of the criteria were ambiguous (*e.g.*, does the external surface area requirement of 120 square feet include the floor?) and two or more of the criteria could be in conflict with one another. This gave us the perfect opportunity to point out that engineers often must rank the criteria for success and determine which parameters are the most important on which to base their "best" design. The final posters varied widely in content and quality, even though guidance on making posters was given in lecture and in email correspondence to the class. However, there are several very good examples that can be displayed to next year's class to improve the overall poster quality (this has been shown an effective technique in past years for other projects).

Conclusion

The Emergency/Homeless Shelter Design Project is an effective activity to lead first-year engineering student teams through the design loop. This project involves many problem-solving methods, and each team must work together and share the responsibilities for the project by assigning tasks. It increases awareness of global and societal concerns by addressing the issues of homelessness and energy efficiency. It introduces engineering simulation packages early into the curriculum and shows students how to use the results in their final design decisions. It provides additional practice with various methods of written and oral communication, including posters, proposals, and pictograms. Finally, the Emergency/Homeless Shelter Design Project gives engineering students an outlet for their creativity and an opportunity to showcase their budding design skills. Our students indicated that this was their favorite project in 2004, and several students admonished us to keep the Shelter Design Project in the project rotation. We will continue to use this project and improve upon it in years to come.

1. Valentine, R., Hornbuckle, K., Stoner, J., Jessop, J. (2003). Engineering Problem Solving I. *ASEE 2003 North Midwest Regional Conference Proceedings CD-ROM edition*.
2. Eide, A.R., Roland, J., Mashaw, L., Northup, L.L. (2001). *Engineering Fundamentals & Problem Solving* (4th ed.). Boston: McGraw-Hill, Inc.
3. Gomez, A.G., Oakes, W.C., Leone, L.L. (2004). *Engineering Your Future: A Project-Based Introduction to Engineering*. Okemos: Great Lakes Press, Inc.
4. (2003, December 13). *Area's homeless need our help*. Iowa City: Iowa City Press-Citizen.
5. Miller, Vanessa (2004, January 27). *Churches plan to open for shelter.* Iowa City: Iowa City Press-Citizen.
6. (2004, March 17). *City must move swiftly on shelter*. Iowa City: Iowa City Press-Citizen.
7. (2004, May 26). *City finally finds spot for Shelter House*. Iowa City: Iowa City Press-Citizen.
8. Engineering Accreditation Commission (2003). *Criteria for Accrediting Engineering Programs.* Baltimore: ABET. Inc.

9. McGourty, J., DeMeuse, K.P. (2000). *The Team Developer: An Assessment and Skill Building Program Student Guidebook*. New York: Wiley.
10. PEER Consultants, P.C. (2004). *Engineers – Scientists – Planners*. Retrieved January 3, 2005, from the World Wide Web: http://www.peercpc.com/aboutus.htm.
11. Sustainable Buildings Industry Council (2004). *Designing Low-Energy Buildings with Energy-10*. Retrieved September 20, 2004, from the World Wide Web: http://www.sbicouncil.org/store/e10.php.
12. The University of Iowa (2004). *The Hanson Center for Technical Communication*. Retrieved January 3, 2005, from the World Wide Web: http://www.engineering.uiowa.edu/%7Ectc/.
13. Engineering Communication Centre (2002). *Proposals*. Retrieved January 3, 2005, from the World Wide Web: http://www.ecf.toronto.edu/%7Ewriting/handbook-proposals.html.
14. University of Idaho (2004). *Letter of Transmittal Outline*. Retrieved January 3, 2005, from the World Wide Web: http://www.class.uidaho.edu/adv_tech_wrt/week14/letter_transmittal_outline.htm.
15. Milligan, A. (2001). Cement and wood-wool combine to improve Philippine housing. *Partners in Research for Development*, *14*, 2-8. <http://www.aciar.gov.au/web.nsf/att/ACIA-5KE7UT/$file/Cement__wood-wooPart14.pdf>
16. PEER Consultants, P.C. & PEER Africa (Pty) Ltd. (no publication date listed). *Passive Solar Technology for 21st Century Communities*. Rockville: PEER Consultants, P.C.
17. U.S. Department of Energy (2004). *Energy Efficiency and Renewable Energy*. Retrieved September 20, 2004, from the World Wide Web: http://www.eere.energy.gov/.

JULIE L. P. JESSOP
Julie Jessop is an Assistant Professor of Chemical and Biochemical Engineering at the University of Iowa. She is actively involved in polymer research and teaches a series of polymer courses in addition to an “Introduction to Literature Review and Proposal Writing” course for first-year graduate students. She received her Ph.D. in Chemical Engineering from Michigan State University.

TONYA L. PEEPLES
Tonya Peeples is an Associate Professor of Chemical and Biochemical Engineering at the University of Iowa. She received her Ph.D. in Chemical Engineering from the John Hopkins University and her B.S. in Chemical Engineering from North Carolina State University. She teaches various Biochemical Engineering courses, and her research includes biological and interfacial catalysis with enzymes and microorganisms from extreme environments.