ENHANCING THE EDUCATIONAL EXPERIENCE IN INTRODUCTORY ENGINEERING COURSES

Dr. Ramakrishnan Sundaram, Gannon University

Dr. Ramakrishnan Sundaram is on the faculty of the Electrical and Computer Engineering department at Gannon University, Erie, PA where he is a Professor. He received his Ph.D. degree from Purdue University. His areas of research include digital signal and image processing, artificial neural networks, and outreach in STEM education.
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Introduction
This paper outlines the restructure of the content and delivery of an introductory engineering seminar course for first-year undergraduate students using core service learning project experiences to shape early student learning of engineering design and practice. The First-Year Seminar in Engineering (FYSE) is a critical entry-level course for undergraduate engineering majors in accredited degree programs (accreditation by the Accreditation Board of Engineering and Technology (ABET)) at institutions of higher education. The course is designed to orient new students to the University and introduce engineering as a professional field. In addition, the course is intended to link knowledge and application of engineering principles to professional ethics and values, and to foster the academic and personal growth of the students. Unfortunately, the previous offerings of this course failed to deliver the desired learning experiences due to (1) the disparate nature of the content and delivery from session to session (2) the lack of continuity across sessions (3) the absence of a common thread to bind the content of the course.

In order to overcome these drawbacks and to teach engineering design and practice in the context of society, ethics, and economics, the course has been restructured\(^1\) by incorporating one or more community-based engineering projects as the core theme\(^2\) of the course. Service learning is of vital importance in the engineering profession\(^3\) and must be integrated into the engineering curriculum at an early stage of career development. Engineering projects with aspects of service learning are both challenging and motivating to students entering the engineering profession after STEM studies at the high school level. In addition to teaching the students engineering design and practice\(^4\) in the context of society and values, and instilling the recognition of engineering issues and concerns, engineering project activity with service learning components incorporates reflection and collaboration as the critically required facets of engineering education.

Community-based engineering projects have clearly identified stakeholders as well as an operating budget for engineering designs to be implemented. The students work in teams to acquire skills related to teamwork, leadership, and project management. In this paper, the approach and implementation of the course redesign based on linking the classroom to the community is discussed. Section 2 provides details of the approach to course redesign. Section 3 identifies the rubrics adopted for project and learning outcomes assessment. Section 4 summarizes the delivery of the redesigned course and the results of project and learning outcomes assessment. The lessons learned and future plans are documented in Section 5.

Section 2: Components of the Redesigned Course
First, the sessions of the course have been reorganized to facilitate the integration around the core theme. The course meets in 28 sessions during the Fall term (14 weeks at 2 sessions per week). Figure 1 illustrates the grouping of the sessions as course modules.
The core theme of the course is to link the course and classroom activities to the community through one or more community-based engineering projects with clearly identified service learning components. These projects are determined by the faculty assigned to teach the course with the Office for Service Learning and the Center for Social Concerns at our University. Funding is provided to each team for their bill of materials. Student teams are organized and project selections are made within the first two weeks of the term. The student teams are expected to follow clearly defined phases of project development.

During the first half of the term, the students (a) identify the issues in the project (b) develop the specifications (c) prepare the conceptual design (d) provide the detailed design (e) develop and submit a proposal for evaluation and assessment by the stakeholders. The stakeholders evaluate the proposals submitted by the student teams based on well-defined criteria such as cost effectiveness, ease of installation, modularity of assembly/disassembly, simplicity, and effectiveness of design. During the second half of the term, the teams of students work on different aspects of the implementation of the chosen design proposal.

Community-based Engineering Design Project

Prior to assigning the project to the students in the course, the following issues related to project identification were addressed and presented to the students as part of Phase 1 of the Service Learning Project.

- Perform an assessment of the need (if the need is not already defined)
- Identify stakeholders (customer, users, person(s) maintaining the project, etc.)
- Understand the Social Context
- Define basic stakeholder requirements (objectives or goals of the project and the constraints)
- Determine the time constraints of the project
The community-based engineering design project which was chosen for implementation by the students during the Fall 2013 offering of the First-Year Seminar Course in Engineering is as follows: Construct a rain water harvesting system, as illustrated in Figure 2, to collect water from the flat roof of a building and deliver the collected water to the storage units for irrigation of a community vegetable garden. The produce from this community vegetable garden, which is maintained by our University, is sent to local and regional food banks and soup kitchens. The motivation for this project is based on the following facts.

(1) Using a rain barrel one can save a significant amount of money in irrigation expenses during a season.
(2) For each inch of rain that falls on 500 square feet of roof, one can collect 300 gallons of water; In most areas of North America, that means one can collect more than a thousand gallons of water a year to use in your containers, houseplants, garden, or water the lawn.

![Figure 2: Rain-water harvesting](image)

First, the following sub-systems of this project were identified.

- Rain-water capture/collection sub-system
  - designed to be **installed on a flat roof-top**
- Pipe interface sub-system
  - **conduit to deliver the collected water to barrels**
- Barrel storage sub-system
  - **designed to operate at ground-level on a raised platform**

Students who were assigned to work on the roof-top rain water collection sub-system had to design water collection system to be placed **on a flat-roof**, shown in Figure 3 (not the sloping roof as is typical and shown in the illustration of Figure 2).
Their design was required to address issues such as
- prevent water-flow blockage on the flat roof
- prevent wind damage to the rain collection system
- effectively collect the rain water
- easy installation and disassembly for future improvement or repaired
- clearly labeled and dimensioned illustrations of all parts
- easy transition and connection to the next subsystem(s)

Students assigned to work on the pipe interface sub-system were required to design the conduit delivery of the rain-water collected on the roof-top to the barrel system placed on a raised platform at ground level alongside the building. Their design would address issues such as
- suitability of the pipe material to
  - effectively carry the rain water
  - reliably interface to the other two sub-systems
- pipe dimensions
  - length, diameter and related specifications for the different sections used
- placement/installation of all pipe sections
  - clearly labeled and dimensioned illustrations of pipe placements and tethers to the building

Students assigned to work on the barrel storage sub-system had to store the water delivered by the piping sub-system using a two-barrel storage system. The design would have to address issues such as
- selection of the appropriate containers and the platform
- overflow connections: between containers, delivery, etc.
- removal of debris to prevent blockage
- clearly labeled and dimensioned illustrations

Team leaders for the students in each sub-system are identified through mutual discussion and an attributes-based selection process. Table 1 shows the schedule for the student teams to develop the design proposal of their sub-system and provide timely deliverables.
Table 1: Schedule for Deliverables

<table>
<thead>
<tr>
<th>Description</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 2 narrative</td>
<td>September 13, 2013</td>
</tr>
<tr>
<td>Phase 3 narrative</td>
<td>September 20, 2013</td>
</tr>
<tr>
<td>Phase 4 narrative</td>
<td>September 27, 2013</td>
</tr>
<tr>
<td>Schematics revision (if needed)</td>
<td>October 4, 2013</td>
</tr>
<tr>
<td>Service Learning Proposal – Design Documentation</td>
<td>October 1, 2013 by 5 pm</td>
</tr>
<tr>
<td>Project Conceptual Review Presentation</td>
<td>October 15, 2013 by 1:30 pm</td>
</tr>
<tr>
<td>Peer Assessment</td>
<td>October 15, 2013 by 1:30 pm</td>
</tr>
</tbody>
</table>

Phase 2 represents *Specifications Development*. The objective of this phase is to determine “what” is needed by understanding the context, stakeholders, requirements of the project, and why current solutions do not meet the need, and to develop measurable criteria in which design concepts can be evaluated.

Phase 3 represents *Conceptual Design*. The objective of this phase is to expand the design space to include as many solutions as possible. Evaluate different approaches and select the “best” one to move forward. Explore “how” to proceed.

Phase 4 represents *Detailed Design*. The objective of this phase is to design working prototype which meets functional specifications.

**Design Documentation**

The student teams received instructions for the preparation of the Design Documentation of the Service Learning Project Proposals. This document would present the details of the design of their sub-system of the project. It would describe the problem being solved and the approach to constructing the solution. It would also include the overall timeline for the project. The document had to clearly contain the following items.

1. **Cover Page**: (complete the enclosed cover page)
   a. Title of proposal
   b. Name and department affiliation of team members
   c. Cost information
   d. Project Summary: a maximum 250-word summary of the objectives, the significance of the proposed activity, and the reasons for choosing the current design of the sub-system of the project

2. **Methodology**: Give a detailed description of the activities to be performed. Indicate procedures (techniques, other people to be involved, specialized equipment, travel, etc.) to be
This is critical, since, if one requires machine shop support of any kind, it must be specified.

3. **Timeline**: Give a detailed time frame for the **construction and installation phases** making sure to identify important milestones, responsibilities and resources. Clearly state the sequence of activities (i.e. step by step) to achieve the final sub-system.

4. **Budget**: Itemize as specifically as possible the funds necessary for the proposed project. Find out where they can be purchased. Use local suppliers (such as Home Depot and Lowe’s). Provide links to items as well as individual costs, include product number when applicable.

5. **Budget Justification**: Give a detailed justification for budget items that are not self-explanatory. Indicate all budget items critical to the project. What is the function of each one of the components?

6. **Schematics**: Detailed schematics of the design (3-D view and individual components as well as dimensions)

**Project Conceptual Review Presentation**

This presentation is made to reviewers external to the team to provide feedback on the design and the process. The presentation would focus mainly on (1) an explanation of the design process (2) the reasons for choosing the current design instead of others (3) schematics of the design and its features/functionalities, and (4) the budget. The Project Review recognizes that the design for projects will be at the earlier stages of the design process, but detailed design components are expected for review. Feedback on the earlier phases of the design process is very important for achieving successful design solutions. Each team has five minutes for the presentation.

**Design Document and Peer Assessment**

The assessment of the Design Document and the Project Conceptual Review Presentation are discussed in the next section.

**Section 3: Rubrics for Assessment**

Rubrics have been developed to assess the following aspects of the Service Learning project on Rain Water Harvesting.

- Design Documentation Proposal
- Project Conceptual Review Presentation
- Intra-Team Peer Assessment
- Sub-System Design

**Rubric for Design Documentation Proposal Assessment**

Figure 4 shows the categories and the evaluation criteria in each category of the rubric used to assess the Design Documentation Proposal completed by each team.
<table>
<thead>
<tr>
<th>Category</th>
<th>Evaluation criteria</th>
<th>Maximum points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format</td>
<td>Readability and flow</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Correctness: grammar and mechanics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spelling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organization</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Completeness of detail, correctness, and technical accuracy</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Title of proposal (2)</td>
<td></td>
</tr>
<tr>
<td>Cover page</td>
<td>Name and department affiliation of team members (5)</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Cost information (3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Project Summary:</strong> maximum 250-word summary of the objectives, significance of project activity, and the reasons for the project design choice (5)</td>
<td></td>
</tr>
<tr>
<td>Methodology</td>
<td>Detailed description of the activities to be performed, procedures, techniques, other people to be involved, special equipment to be utilized</td>
<td>10</td>
</tr>
<tr>
<td>Timeline</td>
<td>Detailed time frame for the construction and installation phases</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>• Identify important milestones, responsibilities, and resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Clearly stated step-by-step sequence of activities to achieve the final sub-system</td>
<td></td>
</tr>
<tr>
<td>Budget</td>
<td>Itemized list including the vendor • links to items, individual costs, product number</td>
<td>15</td>
</tr>
<tr>
<td>Budget Justification</td>
<td>Detailed justification of budget items that are not self-explanatory • Budget items critical to the project are identified • Function of each component is clearly stated</td>
<td>10</td>
</tr>
<tr>
<td>Schematics</td>
<td>Detailed schematics of the design • 3-D view of individual components • Dimensions</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 4: Design Documentation Proposal Assessment Rubric

Rubric for Project Conceptual Review Presentation Assessment
Figure 5 shows the categories and expectations in each category of the rubric for assessment of the Project Conceptual Review presentation made by each team. The presentation made by each team was assessed by the remaining students in the class using this rubric.
Rubric for Intra-Team Peer Assessment
Figure 6 shows the sample of the rubric for assessment of each team member by team by the others only on the same team.

Rubric for Sub-System Design Assessment
Figure 7 shows the sample of the rubric for assessment of the pipe-interface sub-system design from the standpoints of cost, installation, clarity of instructions to assemble/disassemble, design simplicity and effectiveness.
Section 4: Redesigned Course Delivery and Outcomes Assessment
The redesigned First-Year Seminar course in Engineering was taught in the Fall 2013 semester (August 2013 to December 2013) at our University. The following highlights of the delivery are noted.

- Approximately 30 students were enrolled in each of three sections of the class
- Each section was partitioned into six teams with four to five students per team
- Two teams were assigned to work on the design of each sub-system
- Team leaders were identified within each team using an attributes check-list
- Sub-system design proposals from each team were submitted after 7 weeks of the term (mid-term)
- Sub-system design presentations by each team were judged after 7 weeks of the term (mid-term)
- Stakeholders evaluated the proposals from all three sections to chose the design to be implemented during the second half of the term
- Chosen designs of each subsystem built by all the teams assigned to that sub-system from each of the three sections
- Maintenance department of the University engaged for the final assembly of the complete system at the building site
- Student teams submit final report documenting their contributions to the assembled system
- Student teams make presentations to demonstrate evidence of their participation in the assembly of the final system
The course has nine course outcomes as listed below. Each course outcome maps to a specific ABET-approved student learning outcome.

1. Comprehend the basic topics in mathematics, science, and problem solving tools common to the engineering fields
2. Comprehend the engineering design process and problem solving techniques
3. Comprehend how economic, environmental concerns, health and safety, communication, social concerns impact engineering
4. Demonstrate the ability to conduct experiments and analyze data
5. Demonstrate the ability to analyze one of the following LIFECORE dimensions including related activities and presentations: Intellectual (Quest for Knowledge), Life Planning (Balance), Cultural (Appreciation), or Political (Leadership)
6. Demonstrate the ability to relate the following two elements of Catholic social teaching to their own lives: (a) the affirmation of the fundamental rights and responsibilities of every person, (b) the protection of the dignity of work and the rights of workers
7. Demonstrate the ability to analyze what they learned from their engineering service learning experience
8. Demonstrate effective electronic communication and collaboration skills, including the ethical use of computing software and Internet technologies
9. Demonstrate the ability to evaluate personal study habits and develop goals to improve those habits

The course outcomes are assessed by the construction of the Excellent, Adequate, Minimal, Unsatisfactory (EAMU) vectors and their application to the *key assignment* for that outcome. The construction of the EAMU vectors used for course assessment applies the following scoring in all cases: **Excellent** (E) is scoring 90 or better of the total points possible, **Adequate** (A) is 75 or better, **Minimal** (M) is 60 or better, and **Unsatisfactory** (U) is anything below 60. The web-based tool known as Evaltools® is used to gather the evidence for the entire class in each class activity. Table 2 shows the contribution to the score from each assignment/activity in the course. The service learning project report had the largest weight of 20% to emphasize its importance in the course.

Students responded favorably to the use of the community-based engineering project in this course. Sample comments are as follows:

- *Liked the hand-on experience with different engineering tasks*
- *Useful experience gained working in service project*
- *Limit some assignments and labs and grant more time to Service Learning Project*
Table 2: Grade Distribution for the Course

<table>
<thead>
<tr>
<th>Topic</th>
<th>Assignment (K: Key)</th>
<th>Grade (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catholic Social Teachings</td>
<td>Report (K)</td>
<td>2.0</td>
</tr>
<tr>
<td>Life Core</td>
<td>Report (K)</td>
<td>2.0</td>
</tr>
<tr>
<td>Ethics</td>
<td>Quiz</td>
<td>1.0</td>
</tr>
<tr>
<td>Journaling</td>
<td>Individual</td>
<td>16.0</td>
</tr>
<tr>
<td>Homework</td>
<td>Individual</td>
<td>11.0</td>
</tr>
<tr>
<td>Time Management and Assessment (T)</td>
<td>Individual</td>
<td>6.0</td>
</tr>
<tr>
<td>Engineering Design &amp; Public Policy</td>
<td>Team report (K)</td>
<td>5.0</td>
</tr>
<tr>
<td>Review</td>
<td>Individual</td>
<td>4.0</td>
</tr>
<tr>
<td>Measurements / Significant Figures</td>
<td>Quiz</td>
<td>1.0</td>
</tr>
<tr>
<td>ECE engineering lab activity</td>
<td>Lab report (K)</td>
<td>4.0</td>
</tr>
<tr>
<td>ENV engineering lab activity</td>
<td>Lab report</td>
<td>4.0</td>
</tr>
<tr>
<td>ME engineering lab activity - I</td>
<td>Lab report</td>
<td>4.0</td>
</tr>
<tr>
<td>ME engineering lab activity - II</td>
<td>Lab report</td>
<td>4.0</td>
</tr>
<tr>
<td>Experiential learning/Service learning</td>
<td>Report (K) &amp; Presentations (K)</td>
<td>20.0</td>
</tr>
<tr>
<td>ECE engineering project</td>
<td>Final report (K)</td>
<td>8.0</td>
</tr>
<tr>
<td>ME engineering project</td>
<td>Final report</td>
<td>8.0</td>
</tr>
<tr>
<td>Course Exit Surveys</td>
<td></td>
<td>1.0</td>
</tr>
</tbody>
</table>

Figure 8 illustrates the design of the roof subsystem. This design was installed with help from the University maintenance department and is shown in Figure 9. Views of the complete system are shown in Figure 10.

![Figure 8: Roof sub-system design](image1)

![Figure 9: Roof sub-system installed](image2)
Section 5: Lessons Learned and Future Plans

The redesigned First-Year Seminar course in Engineering with the community-based engineering project is a problem-based, project-based, and project-enhanced experience which successfully met and exceeded the following expectations.

- Relate classroom content to engineering problems in the community
- Understand engineering project constraints and requirements in practice
- Develop leadership and communication skills through team work
- Use the experience to strengthen their preparation for future careers in engineering

Additional benefits of this learning experience are (a) goal-oriented, self-directed learning (SDL) to supplement instructor-driven learning (b) promotion of pairing and swarming to help teams of students be more productive and produce higher quality work on the engineering design project. In future, this course will include the following components as well.

- Identify mentors for each incoming engineering student from the following groups (a) senior level students in their chosen major (b) local industry representatives who serve on the engineering curriculum advisory board – these individuals will guide the student throughout their undergraduate degree program at our institution
- Emphasize the relevance of proper laboratory practices and their relation to field activities in the context of the community-based engineering project


