Enhancing the Educational Experience in Introductory Engineering Courses

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Abstract
This paper discusses the restructure of an introductory engineering seminar course for first-year undergraduate students using core service learning project experiences to engage the students in 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, which is offered in the Fall term (August to December), 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. In order to teach engineering design and practice in the context of society, ethics, and economics, the course has been restructured by incorporating one or more community-based engineering projects as the core theme of the course. These projects have clearly identified stakeholders and an operating budget for engineering designs to be implemented. The students work in teams to acquire skills related to teamwork, leadership, and project management. Service learning is important in the engineering profession and must be integrated into the engineering curriculum at an early stage of career development. The students are assigned to teams and 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 proposal chosen to fit well-defined criteria on cost effectiveness, ease of installation, modular assembly/disassembly, simplicity and effectiveness of design is then built by all the students in the class during the second half of the term. The students are re-assigned to teams which work on different aspects of the implementation of the chosen design. This paper will also discuss the rubrics developed for the assessment of learning outcomes.

Introduction

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[1-2] by incorporating one or more *community-based engineering projects* as the *core theme* 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. The paper has five sections. 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

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 prior to the start of the term in discussions with the Office for Service Learning and the Center for Social Concerns at our University. Funding was provided to each team for their bill of materials. Student teams were organized and project selections 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 1, 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.

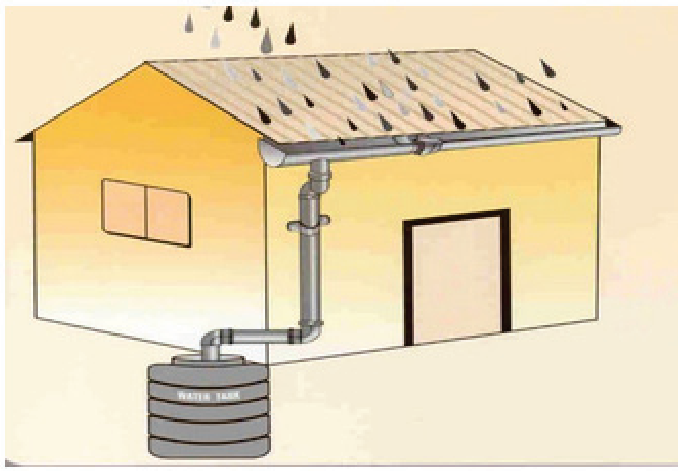

Figure 1: Rain-water harvesting

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 2 (not the sloping roof as is typical and shown in the illustration of Figure 1).

Figure 2: Flat-top roof rain water collection

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 /assembly/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 were 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

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

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 utilized. 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 (1 slide), (2) the reasons for choosing the current design instead of others (1 slide), (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 3 shows the categories and the expectations in each category of the rubric used to assess of the Design Documentation Proposal completed by each team. This rubric evaluates the format and completeness of the document in each of the six categories listed as requirements in the previous section.

Service Learning Project Proposals: Rain Barrel Collection System

Students: ______________________________ Grade: __________/100

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Submitted on time: ☐ Yes or ☐ No (5 points / day late = ______)

Evaluation Criteria	Maximum Points	Score
Format • Readability and Flow • Correctness: grammar and mechanics • Spelling • Organization	15	
Completeness of detail, Correctness and technical Accuracy		
Cover Page • Title of proposal (2) • Name and department affiliation of team members (5) • Cost information (3) • Project Summary: a maximum 250-word summary of the objectives, significance of the proposed activity and the reasons for choosing the project's current design (5)	15	
Methodology Detailed description of the activities to be performed: procedures, techniques, other people to be involved, specialized equipment to be utilized.	10	
Timeline Detailed time frame for the construction and installation phases • Identify important milestones, responsibilities and resources. • Sequence of activities (i.e. step by step) to achieve a final sub-system clearly stated	10	
Budget Itemized list including vendor • links to items, individual costs, product number	15	
Budget Justification Detailed justification for budget items that are not self-explanatory. • Budget items critical to the project are indentified. • Function of each one of the components stated	10	
Schematics Detailed schematics of the design • 3 D view and individual components • dimensions	25	
Total	**100**	

Figure 3: Design Documentation Proposal Assessment Rubric

Rubric for Project Conceptual Review Presentation Assessment

Figure 4 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.

	Evaluating Student Presentations				
Category ↓ Score →	1	2	3	4	Total
Organization	Audience cannot understand presentation because there is no sequence of information.	Audience has difficulty following presentation because student jumps around.	Student presents information in logical sequence which audience can follow.	Student presents information in logical, interesting sequence which audience can follow.	
Subject Knowledge	Student does not have grasp of information; student cannot answer questions about subject.	Student is uncomfortable with information and is able to answer only rudimentary questions.	Student is at ease with expected answers to all questions, but fails to elaborate.	Student demonstrates full knowledge (more than required) by answering all class questions with explanations and elaboration.	
Graphics	Student uses superfluous graphics or no graphics	Student occasionally uses graphics that rarely support text and presentation.	Student's graphics relate to text and presentation.	Student's graphics explain and reinforce screen text and presentation.	
Mechanics	Student's presentation has four or more spelling errors and/or grammatical errors.	Presentation has three misspellings and/or grammatical errors.	Presentation has no more than two misspellings and/or grammatical errors.	Presentation has no misspellings or grammatical errors.	
Eye Contact	Student reads all of report with no eye contact.	Student occasionally uses eye contact, but still reads most of report.	Student maintains eye contact most of the time but frequently returns to notes.	Student maintains eye contact with audience, seldom returning to notes.	
Elocution	Student mumbles, incorrectly pronounces terms, and speaks too quietly for students in the back of class to hear.	Student's voice is low. Student incorrectly pronounces terms. Audience members have difficulty hearing presentation.	Student's voice is clear. Student pronounces most words correctly. Most audience members can hear presentation.	Student uses a clear voice and correct, precise pronunciation of terms so that all audience members can hear presentation.	
				Total Points:	

Figure 4: Project Conceptual Review Presentation Assessment Rubric

Rubric for Intra-Team Peer Assessment

Figure 5 shows the sample of the rubric for assessment of each team member by team by the others only on the same team.

Please complete the following honestly and objectively – the results are kept confidential.

Each member conducts the evaluation as an individual task. You should not discuss and decide upon the ratings as a team. All members of your team, **including yourself**, are listed in the table, below.

You are given 100 points **for each of the four attributes**. Your task is to allocate them among your teammates in proportion to their contribution to each attribute. Evaluate **each member**, **on each of the team-work attributes** (*Enthusiasm & Commitment, Technical Contribution, Dependability & Cooperation, and Communication*), relative to their effort on the year-long, service project activities.

Enthusiasm & Commitment :: ***Leader? Built Cohesion? In-Charge Person?***
Technical Contribution :: ***Materials / Process Insights?***
Dependability & Cooperation :: ***Reliable? Team Support? Enabler?***
Communication :: ***Interpersonal Skills? Articulate? Clear?***

Group A1: Rain-Water Collection

Your Name:____________________

Name	*Enthusiasm & Commitment*	*Technical Contribution*	*Dependability & Cooperation*	*Communication*
	⇓ Σ 100	⇓ Σ 100	⇓ Σ 100	⇓ Σ 100

* Team Leader
Comments ?

Figure 5: Intra-Team Peer Assessment Rubric

Rubric for Sub-System Design Assessment

Figure 6 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.

Pipe Interface Sub-System Criteria	Score
Cost effectiveness: • List the total cost of the subsystem, the lower the better • Identify the cost of each item and possible vendor • Suitability of pipe material	0-10
Ease of Installation and Disassembly: • Modularity: subsystem put together/taken apart in a modular manner is better than single-piece of design • Size: pipe sections which can be carried by one person for installation is better than that which requires more than one person	0-15
Clarity of instructions: • Implementation diagram is easy to understand and follow • All parts are clearly labeled and complete • No on-site decisions for part(s) installation/re-installation	0-10
Simplicity in design: • Fewer the number of parts, the better the design • Design layout looks professional	0-20
Effectiveness of design: • Design takes into consideration possible damage/failure due to change in weather conditions – wind, rain to snow • Shows detailed and clear transition to the roof-top collection subsystem and the barrel storage subsystem	0-20
TOTAL POINTS	75

Figure 6: Sample of the Sub-System Design Assessment Rubric

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

Section 5: Lessons Learned and Future Plans

The redesigned First-Year Seminar course in Engineering with the community-based engineering project was a *problem-based*[5,6] *project-based*[7-9] and *project-enhanced*[10] 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)[11,12] to supplement *instructor-driven learning* (b) promotion of *pairing*[13] and *swarming*[14-15] to help teams of students be more productive and produce higher quality work on the engineering design project.

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