Teaching first year engineering students engineering design process and problem solving through service learning projects

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***Abstract*—This paper presents the authors' practice of teaching first year engineering students the engineering design process and problem solving through service learning projects (SLPs). The SLPs are embedded in the First Year Seminar in Engineering, a first semester freshmen level course that all engineering freshmen at Gannon University are required to take. The SLP, identified by the combined effect from the course instructors, the university SL director, and the project stakeholder, lasts for the entire semester. Students, divided into several design teams, are given very specific step-by-step design guidelines to follow. During the design process, students are practicing how to approach and interpret the engineering design requirements, formulate engineering problems, propose different designs, and eventually solve the problem and evaluate the final product. This paper will walk the readers through each step of SLP from instructing point of view. It will present the challenges faced by students and the instructors and how to overcome them. It will also report on the lessons learned from the project. The student assessment and course evaluation will be presented and discussed as well.**

Keywords—engineering design, problem solving, service learning

I. INTRODUCTION

Project-based learning and Service-learning are two rapidly growing pedagogies in higher education [1-9]. Project-based service learning combines the characters of both and "is a form of active learning where students work on projects that benefit a real community or client while also providing a rich learning experience." It enhances student preparation to practice engineering design when applied in engineering disciplines [1].

At Gannon University, every engineering freshmen student is required to take the First-Year Seminar in Engineering (FYSE) course, a required Liberal Core 2-credit course [10-13]. Four of the nine course outcomes are specific to engineering majors. Two of which are "Be familiar with the engineering design process and problem solving techniques" and "Demonstrate the ability to analyze what they learned from their engineering service learning experience." A semester long, community-based service learning project (SLP) is employed to meet these two course outcomes. In addition, this course is also selected to meet ABET Student Outcomes in different majors at freshmen or introductory level. Outcome e, "ability to identify, formulate, and solve engineering problems," is common to the engineering majors represented in this course.

In the past few years, an array of engineering SLPs have been identified and completed in the university's community garden [14]. These projects included campus rain garden design, rain water collection [13], trellis design and construction, vermicomposting prototype, and integrated pest management guide. Due to the increased demanding and the limitation of the horizontal space, in fall 2014 the garden stakeholders were interested in exploring ways of growing vegetables vertically to yield more produces. As a result of the combined effect from the garden stakeholder, the FYSE instructors, and the university service learning director, the vertical planter project was identified as the SLP for fall 2014.

II. VERTICAL PLANTER SLP OVERVIEW

Multidisciplinary teams of five-to-six students were created with six to seven groups in one section. The first half of the semester was dedicated to complete a design proposal while during the second half of the semester, the selected designs were built; typically one per section of FYSE.

As shown in Table 1 there are only seven in-class lecture sessions dedicated to SLP. Since the majority time that students spend on the SLP is outside class time, the close guidance and following up is very important to ensure the success of the process. The description of the typical timeline employed for any project follows using the vertical planter project as the example. The engineering design is introduced early in the semester to the class. It is followed by the introduction of the SLP. The third lecture session teaches students the theory and literature about problem solving. Students then have three weeks to work toward a design proposal and a proposal presentation. All the teams are required to submit a re-design to improve the selected proposal. The winning planter was selected and after the SLP construction duties were divided among all teams with clear timeframes, students have another five weeks to get the vertical planter assembled.

TABLE I. FIRST-YEAR SEMINAR IN ENG., FALL 2014 SCHEDULE

Session #	Topic
1	Introduction and Succeeding in Classroom
2	Life Cores and Time Management
3	Engineering Design
4	Service Learning Project
5	Introduction to Engineering Disciplines and Challenges
6	Introduction to Engineering Disciplines and Challenges
7	Problem Solving
8	Teamwork
9	Leadership
10	Catholic Social Teachings
11	Informational Literacy and Library Tour
12	Engineering and Public Policy
13	Ethics
14	Service learning - Proposal Presentations
	Mid-Semester Break
15	Measurements, Units, Approximation and Estimation
16	Service learning project - Construction Duties
17	Engineering Lab Activities - ECE, ENV, ME
18	Engineering Lab Activities - ECE, ENV, ME
19	Engineering Lab Activities - ECE, ENV, ME
20	Engineering Lab Activities - ECE, ENV, ME
	Advising Day
21	Final Engineering Project Overview - ME / ECE / ENV / BME
22	Final Engineering Project Implementation
23	Final Engineering Project Implementation
24	Engineering Work Experience: Benefits
	Thanksgiving Break
25	Final Engineering Project Implementation
26	Study Abroad / Student Engineering Societies
27	Service learning project at site
28	Service learning assessment
	Final presentation and wrap-up

III. DETAILED DESIGN PROCESS

The 10 steps engineering design process as shown in Figure 1 is adopted for the SLP. The following sub-sections are dedicated to the presentation of how to teach/guide first year engineering freshmen students during the major steps of the engineering design process and problem solving.

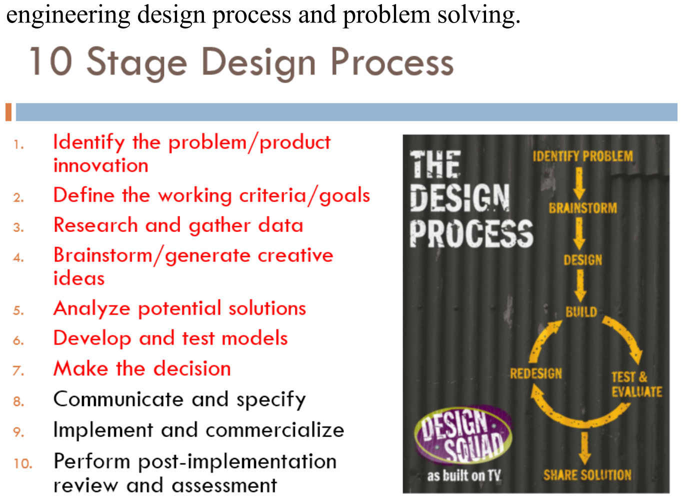

Fig. 1. Ten step engineering design process lecture note [15-17]

A. Define goals, research and gather data

After the problem (design vertical planters for best produce yield) was identified, students moved on to the defining the working criteria/goal stage. In week 2 of the semester, the university service learning director and the community garden stakeholders were invited to give a brief introduction about the SLP to the students. Time was reserved for students to ask questions related to the design requirements and goals. Students were encouraged to go to the garden site, take pictures and make measurement for first-hand information.

The following were five design constraints outlined for this project:

1. Select a fruit, vegetable or herb to grow. It must be suitable for the region's climate.
2. Design must be specific for the selected produce
3. Maximize the yield of the produce
4. Maximum cost $150.00
5. Purchasing off-the-shelf product without any additional modifications is not acceptable. Modifications must be substantial.

In addition, the following requirements were stated during the project definition stage:

- All levels of the vertical planter must be accessible with a 3' step stool for harvesting
- Materials employed should be environmentally friendly
- Employ recyclable materials for the structure to the largest possible extend
- Easy installation and disassembly for future improvements or repairs
- Two options for support: free standing, or placed against one of the walls in the garden. The wall to be used must be specified.

B. Brainstorm/generate creative ideas and analyze potential solutions

With the design constraints and requirements in hand, students were off to a good start. Going into the next step, students were guided to hold brainstorming sessions and to share with each other all ideas. The monitored discussion sessions were very inspiring but without any formal engineering design experience, students' effort can easily be diverged and the focus can be lost at any time in the process. To direct students to a right direction, teams were required to submit three status reports leading to a written design proposal and a presentation before mid-semester break. The status reports, adapted from the EPICS program [17], guided the students through the design process. The status reports were the building blocks for a complete proposal. Table II presents the details of each status report.

TABLE II. PROGRESS REPORTS LEADING TO A DESIGN PROPOSAL

Reports	Goal	Content/Evidence
Status Report #1	Specification development /understand what is needed	Context description, mock-ups, definition of user interaction, identification of other solutions and benchmarks, clarification of customer requirements
Status Report #2	Select the best solution out from serval possible ones	Brainstorm several possible solutions, prior artifacts research, modification with user feedback, feasibility of potential solutions, selection of "best" solution
Status Report #3	Design (on paper or digital) working prototype	Bottom-up development of components, design specification for components, shematics, exploration of failure modes, tools needed
Proposal	Details of the design, the problem to be solved and construc the solution	Project summary, detailed description of proposed design, shcematics, methodology and timeline, budget and justification

The first progress report focuses on specification development. Its goal is to understand "what" is needed by understanding the context, stakeholders' requirements of the project, and to develop measurable criteria in which design concepts can be evaluated. At this stage, each group started with selecting a produce which is suitable for region's climate as well as meets stakeholders' high-yield needs. The selected produce should also be suitable to grow vertically. Then the students search online to identify at least five available benchmark products to compare. Students were reminded frequently to communicate with the project stakeholders and the course instructors to ask questions and get feedbacks.

The second progress report focuses on conceptual design. Its goal is to expand the design space to include as many solutions as possible. At this point, students evaluate different approaches and select the "best" characteristics to move forward. Equipped with clear specifications, benchmark products and creative ideas, at this stage, students are exploring "how". They are guided to come up with several possible vertical planters for the selected produce. The construction of simple prototype follows using everyday items such as paper cups, wood sticks, tapes, Styrofoam, card board, etc. Based on user's feedback and comparison, the students choose the "best" solution with rational statement.

TABLE III. VERTICAL PLANTER SELECTION CRITERIA

Vertical Planter Criteria	Score
Cost effectiveness: • List the total cost of the system, the lower the better • Identify the cost of each item and possible vendor	0-10
Ease of Installation and Usage: • Easy installation and disassembly for future improvements or repairs • Size: setup that can be carried by one person is better than one that requires more than one person for installation/transporting/maintenance • Vertical planter must be accessible with a 3' step stool for harvesting	0-20
Clarity of instructions: • Implementation diagram is easy to understand and follow • All parts are clearly labeled and complete • No on-site decision for part installation	0-10
Simplicity in design: • Fewer parts the better • Design layout looks professional	0-20
Effectiveness of design: • Maximizes the use of space • Maximized the yield of the produce • Design takes into account failure modes (i.e. wind effect) • Stable supporting structure defined	0-30
Material selection • Selected environmentally friendly materials • Maximized the use of recyclable materials	0-10
TOTAL POINTS	100

The stage three progress report focuses on detailed design. Its goal is to design a working prototype which meets functional specifications. The following items need to be completed:

- Dimensions for the planter and each part of the planter
- Type of material for each part of the planter, quantity of each component.
- Specify any tools or services needed for planter construction and installation.
- Itemized budget and budget justification.
- Explore failure modes and discuss how the proposed design will avoid the failure modes.
- Prepare 3D view of the planter and individual components. Dimensions need to be included.

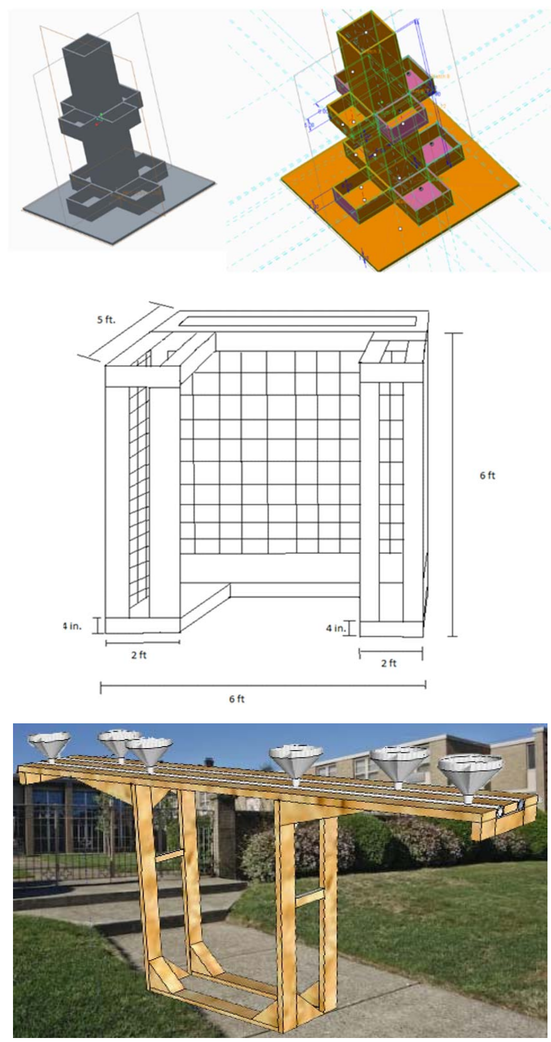

Fig. 2. Unselected planters for (a) herbs or peas (b) beans or cucumbers and (c) potatoes or beats (with hanging basket and automatic watering system)

The combination of the above described progress reports leads to a design proposal and a group presentation. The proposal is required to follow a specific format and template. It includes

- a summary page
- the detailed description of proposed design

- the planter schematics (3D digital view as detailed as possible)
- the methodology and timeline
- itemized budget with links to items as well as individual cost and quantity
- budget justification

The group presentation was judged by course instructor, other student teams, and the stakeholders. The proposals were evaluated based on the vertical planter criteria, as listed in Table III, which were developed by the combined effort of course instructors and the stakeholders. For each class section (with six to seven groups and 30+ students), only one produce/planter was selected as the winning proposal. This winning proposal acts as “the” planter for the entire class to move on to the construction stage. The rest of the non-winning teams are reassigned different duties and switch their time and effort fully to the winning planter’s redesign and construction. Figure 2 displays some of the unselect planters, which shows a good variety of good ideas.

IV. DESING CONSTRUCTION AND INSTALLATION

Right before midterm break, students completed the so-called “design on paper”. The winning planter from one of the sections was a vertical tomato planter made with PVC pipes and connectors; this design will be employed her to continue to describe the design process. In the second half of the semester, the entire class with six groups worked together to redesign the planter, purchase materials, construct and install the planter. The winning team assumed the leading role position to lead the effort of the project implementation. First the designed planter was revisited and modified further to optimize its performance, strength and durability. After the redesign is finalized, each of the six groups is assigned to a specific job and timeline to contribute to the implementation of the project. The following steps ensure that the project is successfully completed on time:

1. To finalize the itemized budget and verify purchasing/ordering links and vendors. The winning team took on this job. They confirmed the online purchase links, went to local hardware stores for quick order of some of the components, and went to local specialized hardware shops for several unique pieces which either is out of stock online or not available.

Fig. 3. Sample pictures of the PVC pipes and diffferent types of connectors

2. To complete the purchase and transport all the supplies to assigned location. With the help from the course instructor and the university Service Learning Office personnel, one group successfully followed up and completed this job. They coordinated with the university mail office and visited local stores several times to gather all the materials. Figure 3 shows a couple of sample pictures of the pipes and connectors.

3. To prepare all supplies for required manufacturing processes based on schematics. For this project, it required to mark all the 22 long pipes. This is a crucial step of the project. At the beginning the group assigned to this job did not pay sufficient attention to the accuracy of the marking. As a result, two extra pipes were ordered to make up the loss of the unusable pieces. Based on Figure 4, it can clearly be seen that there are three different length pipe pieces, 18’’, 8’’, and 12’’. The purchased standard PVC pipes are 10’ long each. Special care needed to be taken when marking each pipe to obtain the optimum combination of above three lengths. Special attention also needed to be given to the “mark error” for one piece and the “accumulated error” from a few pieces located on one pipe. For example, theoretically, one 10’ PVC pipe should be able to yield 10 pieces of 12’’ long pipe segments. But with error accumulation, the last piece left could be either much shorter than 12’’ or much longer than it, but not close to it. For either case, the marking resulted in uneven length of the pipe segments which lead to waste of extra pipes and difficulty during the assembly stage. The good news is that the group who was engaged in the marking job quickly realized the issue and made efforts to correct it before a much bigger waste took place. Figure 5 shows a couple of pictures of the marked piece and working station.

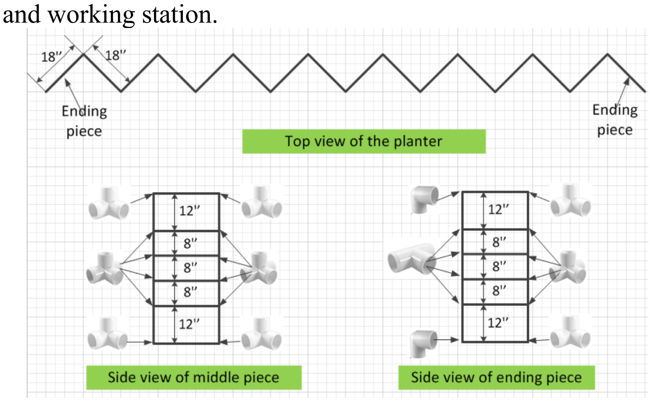

Fig. 4. The schematic of the tomato planter made with PVC pipes and connectors

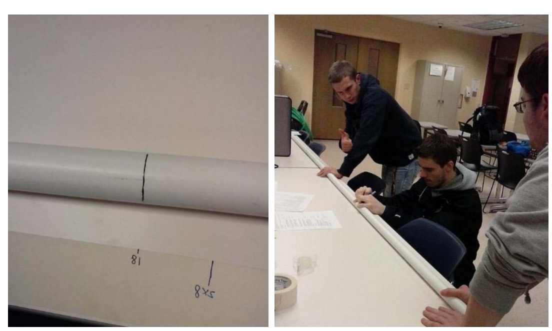

Fig. 5. Marked pipe line and the marking working station

4. Manufacturing Processes and logistics. For this project, this included the transportation of all the 22 pipes to the cutting station and cutting off all the pieces. The dedicated working location was on the 3rd floor while the mechanical shop, where the cutting machine was located, was on the first floor. The group that has this job transported all 22 long pipes to the cutting shop based on preset schedule. They took turns operating two different cutting machines and cut the 181 pieces out of the pipes. Figure 6 shows the picture of one cutting station.

5. Quality Control. For this project, this step required to check the accuracy of the length of each of the 181 pieces. This was a very time-consuming and patience demanding job which was completed excellently by one group. This ensured the planter assembly stage to be highly efficient and smooth. This group also preassembled one segment of the planter to verify the accuracy of the project so far. Figure 6 shows the picture of that segment.

Fig. 6. Cutting station where students cut the PVC pipes to piece with different length and one segment of the planter

6. To assemble all parts.. The assembly of the planter was a rather quick job to do due to the excellent execution of previous steps. Figure 7 shows the fully assembled tomato planter (wall) in the lab. It took roughly less than half an hour to complete the job which verified one of the design requirements---easy assemble/disassemble.

Fig. 7. Fully assemble tomato planter (wall)

V. Assessment and Evaluation

A standard course exit survey is administered at the end of the semester. The first section asks students to evaluate the achievement of the course learning outcomes (refer to Table IV). The second course outcome states "Be familiar with the engineering design process and problem solving techniques". Since 2011 when the *semester long* community-based design project was incorporated, the students have consistently agreed that they have become familiar with engineering design and problem solving techniques. Additionally, TABLE IV. presents the mean of the students' response to the course outcome associated to the service learning experience; no significant changes have been observed since 2011 when the service learning projects were adopted. As the years have progressed, the service learning project has been embedded into the lectures and discussions related to engineering design and problem solving, allowing for an efficient theme for their application.

TABLE IV. Relevant Course Outcomes' mean responses to Likert scale of 5 (Strongly Agree) to 3 (Neutral) to 1 (Strongly Disagree).

Outcomes / **Year_Section (responses)**	2 - Be familiar with the engineering design process and problem solving techniques	7 - Demonstrate the ability to analyze what they learned from their engineering service learning experience	Overall were the course outcomes (1-9) achieved
Fall_2010_01 (19/22)	3.4	3.1	3.5
Fall_2010_02 (18/21)	3.9	4.0	4.0
Fall_ 2011_01 (23/24)	3.9	4.1	4.0
Fall_ 2011_02 (24/27)	4.0	4.0	3.9
Fall_2012 (51/58)	4.0	3.9	3.9
Fall 2013 (25/26)	4.2	4.0	4.1
Fall 2014_01 (33/33)	4.5	4.2	4.1
Fall 2014_02 (32/35)	4.1	4.2	4.0
Fall 2015_01 (35/35)	4.4	4.3	4.3
Fall 2015_02 (25/28)	3.8	3.9	3.8

A Liberal Studies Assessment Report is generated at the end of the course by the instructors where five of the course outcomes are evaluated based on students' submitted artifacts (*key assignments*). EAMU vectors are applied to the *key assignments*. The construction of the EAMU vectors used for this 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 assessment of the common Liberal Studies outcome related to the service learning experience is presented in TABLE V. As observed, through an objective assessment of the key assignments, the course outcome is adequately met. This is expected achievement level for an introductory course.

TABLE V. BASED ON EAMU VECTOR ASSESSMENT OF THE COMMON LIBERAL STUDIES OUTCOME RELATED TO THE SERVICE LEARNING EXPERIENCE.

Year_Section	*EAMU vector*
Fall 2014_01	A 88.08%
Fall 2014_02	A (86.5)
Fall 2015_01	83.52%
Fall 2015_02	A (78%)
Fall 2015_03	M (72.4)

The SLP was also aiming towards one common ABET Student Outcomes "ability to identify, formulate, and solve engineering problems". But since this course is scheduled at the freshmen first semester and the engineering design process is at the introductory level, the assessment evidence was not specifically collected for ABET evaluation. Upper level major courses (including reinforce and mastery levels) were selected to collect those evidences to demonstrate that students have met above ABET student outcome.

VI. CONCLUSIONS AND LESSONS LEARNED

Community-based design projects, referred to as service learning projects in this work, can act as the centerpiece in introductory courses providing a platform to apply engineering design concepts and problem solving techniques. SLPs are successful at addressing the social impact of engineering solutions early in the students' careers as well as course outcomes.

Lessons Learned: The following list provides a guide for any faculty wishing to adapt this model to some degree.

- *Connect the project to as many aspects of the course as possible*. The project can be employed as the center-piece of the course. This requires detailed preparation from the instructor's part.
- *Emphasize the social aspect of the project*. Students buy-in will make the semester long project more enjoyable and successful.
- *Different skill sets, different needs*. The background of first-year students is very diverse and resources should be available to accommodate for different needs.
- *Constant guidance and feedback is needed*. Students need to be coached closely during each step of the process. Freshmen tend to get side-track at time especially when they are not familiar with the different steps of the design process.
- *Logistics are critical*. Materials, supplies, tools and machine shop support are needed and should be secured early on. A working/storage is required.
- *Connect several assessment methods to the project*. Sufficient weight in the overall course grade will ensure students' effort.
- *Funds are needed to complete the project*. Money should not be the reason why a project is not implemented when the cost is reasonable especially after students have devoted a large amount of time to the development of an idea.
- *Get ready to spend extra time*. The introduction of service-learning project requires additional time from faculty and students. Faculty need to ensure that the scope of the project is appropriate for the allocated time and students' skills.
- *Stakeholders need to understand the goals*. When service learning projects are incorporated, it is important to explain stakeholders that the project lives inside an academic course with student learning objectives. A four-month cycle, from project definition to implementation, requires prompt feedback to students' questions.

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