Impacts of Service-Learning Projects on the Technical and Professional Engineering Confidence of First Year Engineering Students

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Abstract

First-year engineering students at Loyola Marymount University (LMU), a primarily liberal arts private undergraduate institution, can participate in service-learning projects through an engineering living-learning community. In addition, service-learning projects were recently offered at LMU for first-year engineering students not participating in this living-learning community. The impact of service-learning on students’ engineering design self-efficacy and engineering learning outcomes were assessed. An instrument was adapted from a combination of previously validated instruments that measure engineering design self-efficacy and interventional impacts on technical and professional engineering learning outcomes. The instrument also includes a reflection component on personal development, social impact, academic enhancement, university mission, and ethics. A mixed-methods approach was used to examine differences between first-year engineering students who participated in service-learning projects during the fall semester of 2014 and those who did not. Students participating in service-learning projects showed significantly higher gains in confidence in both technical and professional engineering skills. Female students in particular showed the most dramatic gains, with an average increase of 81.6% in technical engineering confidence as a result of their service-learning course. The higher gains in confidence can be attributed to the students learning more about how to identify and understand stakeholder needs and design requirements.

Introduction

Service-learning in the engineering disciplines utilizes service as a vehicle for both professional and technical knowledge gains. The use of service in engineering education in the United States began in the 1990s (e.g., see Tsang et al. and Duffy) and has recently increased based on the need to reconsider the priorities of the professoriate, a desire to improve human conditions to fulfill higher education goals, and to meet the interest and demand of students and faculty across the nation. Many engineering programs are exploring ways to offer new and meaningful service experiences for their students.

Since 2009, first year engineering students at LMU, a primarily undergraduate private liberal-arts institution, could participate in service-learning projects through an engineering living-learning community (LLC). This LLC is named Program for an Engineering Education Community (PEEC) and has included six student cohorts since its inception. The PEEC program is designed with a 3-credit introduction to engineering course in the fall semester followed by a 1-credit course in the spring, with the intention that the service project planning occurs in the fall and implementation in the spring. Of the approximately 110 incoming first year engineering students each year, the program is limited to about 25 students per year and continually reaches full capacity. Students are selected for the program based on interest and to create as much academic, ethnic, and gender diversity as possible. Past projects have included designing and installing a playground and a greywater irrigation system at a transitional residence for single women and
women with children, conducting water quality and hydrologic measurements in a wetland, and designing engineering lesson plans and activities for a public STEM elementary school. The 2014 PEEC cohort continued the work with the elementary school to develop engineering lessons plans and design competitions for students involving solar cars, water filters, and a geothermal plant. These projects were selected in conjunction with the school staff to highlight the features in the school’s LEED-certified infrastructure and surrounding habitat.

LMU first year engineering students not enrolled in PEEC were also given the opportunity to participate in a service-learning project in 2014 as part of their introduction to engineering course. In particular, these students partnered with the teachers and students at WISH Charter, a public K-8 charter school dedicated to providing an inclusive educational environment for all children. Teams of engineering students were paired with an individual classroom and worked to design engineering solutions to meet the particular needs of that classroom and teacher. Projects ranged from designing engineering lesson plans, building interactive demonstrations of different engineering concepts, and creating custom assistive devices for students with disabilities. The WISH Charter students learned about the engineering design process and design thinking by building and testing rubber band cars, designing and building wooden bridges, and designing a random name generator for their teacher. The engineering student teams also built different interactive pulley demonstrations, a large solar system model, a beanbag catcher, a camera vision system for a student who is legally blind, and a fidget chair. The teams followed the project timeline and completed various deliverables as shown in Figure 1 (the fidget chair project is used as an example).

<table>
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<tr>
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<tbody>
<tr>
<td>Deliverables:</td>
<td>Deliverables:</td>
<td>Deliverables:</td>
</tr>
<tr>
<td>• Concept Gallery Walk</td>
<td>• Preliminary Demo</td>
<td>• Engineering Fair at partner location (WISH Charter)</td>
</tr>
<tr>
<td></td>
<td>• Initial Report</td>
<td>• Final Report</td>
</tr>
</tbody>
</table>

*Figure 1. Example engineering service-learning project phases, timeline, and deliverables.*
Broadening our offerings for service-learning opportunities places greater emphasis on studying the impact of these interventions to maximize their benefits and to measure the value added. Studies indicate that the knowledge and skills gained by students participating in service-learning projects are at least on par with gains from traditional project-based learning. According to Barrington and Duffy (2010), general benefits to students include increases in subject matter comprehension, GPA, retention, critical thinking skills, tolerance for diversity, writing skills, and citizenship. Specific gains in both professional and technical skills have been reported. For example, in a recent study by Carberry et al. (2013), engineering students on average identified that 45% of what they have learned about technical skills and 62% of what they have learned about professional skills was gained through their engineering service experience. Female students credited service experiences as their source of both professional and technical skills significantly higher than male students, which was consistent across academic years. Furthermore, Swan & McCormick (2009) found that students with service-learning experience scored better in technical areas on measures of analytical, practical and creative skills.

This paper builds from past scholarship and continues these efforts to understand the added value of offering service-learning opportunities in first year engineering courses by examining how such experiences impact student confidence with various technical and professional engineering skills.

**Research Methods**

A mixed-methods approach was used to assess the impacts and added value of service-learning on the 2014 first year engineering students at LMU. A total of 111 students were enrolled in four sections of introduction to engineering during the fall semester of 2014. Two sections (with 56 students total) followed a traditional course format that focused on different project modules, such as designing and testing water filters, building and testing small-scale wooden bridges, and programming a robot. Two sections (with 55 students total) implemented a service-learning project, as previously mentioned. Pre and post assessments of the participating students were conducted. Demographic information was also collected to monitor if differences arose between students grouped by specific demographic factors. The assessment was conducted in accordance with approved Institutional Review Board procedures and participation by students was voluntary.

**Engineering Design Self Efficacy and Learning Outcomes**

Changes in student confidence in both technical and professional skills were quantitatively measured. An instrument was created using a combination of a previously validated engineering design self-efficacy instrument and a modified version of the validated National Engineering Students’ Learning Outcomes Survey (NESLOS) instrument. Self-efficacy, or an individual’s confidence about his or her ability, is shaped by experiences, persuasions, and physiological states. The inclusion of a measure of engineering design self-efficacy will provide a gauge of how the service-learning projects impact student confidence in conducting various engineering design tasks. The NESLOS instrument measures both technical-engineering
design subject–matter knowledge and professional–personal skills. Pre- and post-course, all students were asked to rank their confidence on a sliding scale from 0-100 as it relates to various technical and professional skills. The instrument is included in Appendix A. The average percent change in self-reported confidence from pre to post intervention was determined for each question.

**Critical Reflections**

Reflection is an integral component of service learning, as it requires students to evaluate the connections between their service experience and the overall learning outcomes goals. At the conclusion of the course, all students were invited to qualitatively reflect on what they learned in terms of personal development, social impact, academic enhancement, university mission, and ethics\(^\text{13}\). Students were asked to pick and respond to two out of five reflection prompts. The instrument is included in Appendix B. An open-coding approach was taken to identify emergent categories in the reflection responses\(^\text{14-15}\). One member of the research team first read each student’s response to determine a set of categories compiled into a rubric. The rubric was then used to code each student’s response. A second rater then used the rubric to test its reliability across raters. A second member of the research team coded each student’s response using the first rater’s codes until agreement was reached. Changes to the coding rubric were made to establish a high inter-rater reliability between the two raters.

**Results**

**Engineering Design Self Efficacy and Learning Outcomes**

A total of 72 students completed the pre and post assessment instruments, representing an overall response rate of 65%. The student responses to all of the engineering design self-efficacy and learning outcome questions were averaged and the percent increase from pre to post was determined, as shown in Table 1. Data is presented for all students participating in the traditional course and the service-learning course. Responses from female students were isolated and are presented. A paired two-sample t-test was conducted to determine the p-value of the percent increase from pre to post, the majority of which were found to be less than 0.01.

In general, female students had a slightly lower average confidence level with their technical engineering skills coming into both courses (average of 50.4), in comparison to all of the students combined (average of 56.4). However, the confidence levels in technical skills of the female students were equal to that of all students in the traditional courses post intervention. Similarly, female students in the service-learning courses had similar post confidence levels in technical skills compared to all students combined. All students in the service-learning courses had higher post confidence levels with technical engineering skills in comparison to all students in the traditional courses. In addition, female students who participated in the service-learning courses had higher post confidence levels in technical skills compared to female students who were in the traditional courses.
All students were fairly equal at the beginning of the courses in regards to their confidence in professional skills. Students who were in the service-learning courses had higher post confidence in professional skills compared to students in the traditional courses, with no observable differentiation between female students and all of the students combined.

The average percent increase in student confidence from pre to post is presented in Table 1 and Figure 2. The error bars in Figure 2 represent the standard error of the mean. All students who participated in the service-learning courses reported higher gains in both technical and professional confidence when compared to students in the traditional courses. Female students in the service-learning courses showed similar increased gains in confidence. The most pronounced shift was the increased confidence in technical engineering skills for female students who participated in service-learning projects, with an average percent increase in confidence from pre to post intervention of 81.6%.

Table 1. Average pre and post student confidence and percent increase in confidence in technical and professional engineering skills.

<table>
<thead>
<tr>
<th></th>
<th>Technical Engineering Skills</th>
<th>Professional Engineering Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Traditional Course</td>
<td>All Students</td>
<td>Females</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>All Students</td>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>Females</td>
<td>40</td>
<td>14</td>
</tr>
<tr>
<td>Service-Learning</td>
<td>All Students</td>
<td>Females</td>
</tr>
<tr>
<td></td>
<td>n</td>
<td></td>
</tr>
<tr>
<td>All Students</td>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>Females</td>
<td>40</td>
<td>14</td>
</tr>
</tbody>
</table>

* p-value < 0.05 and ** p-value < 0.01
Student responses from individual questions regarding confidence in specific technical engineering skills were further investigated. In particular, the pre and post data from questions that related to identifying, understanding, and establishing design requirements and the design and stakeholder needs (questions 2 through 4 in Appendix A) are listed in Table 2. The average percent increases in student confidence from pre to post are also presented for these three specific technical engineering skills in Figure 3. The error bars in Figure 3 represent the standard error of the mean. The data trends were very similar to those shown in Table 1 and Figure 2. In general, all students participating in the service-learning courses showed higher gains in confidence than students in the traditional courses. Moreover, the most significant gains were among the female students who participated in the service-learning projects as they reported higher gains in confidence in their technical skills than their peers.
Table 2. Average and percent increase in student confidence with technical engineering skills related to design and stakeholder needs and requirements.

0 = Low confidence  50 = Moderate confidence  100 = High confidence

<table>
<thead>
<tr>
<th>Technical Engineering Skills</th>
<th>All Students</th>
<th>Females</th>
<th>All Students</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>2. Identify a design need</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Increase (%)</td>
<td></td>
<td>Increase (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>39.1**</td>
<td>33.1</td>
<td>47.4**</td>
<td>89.0**</td>
</tr>
<tr>
<td>3. Understand the needs of the various project stakeholders</td>
<td>34.5**</td>
<td>25.2</td>
<td>44.0**</td>
<td>81.5**</td>
</tr>
<tr>
<td>4. Identify and establish design requirements and constraints</td>
<td>42.8**</td>
<td>32.5*</td>
<td>52.7**</td>
<td>107.4**</td>
</tr>
</tbody>
</table>

* p-value < 0.05 and ** p-value < 0.01

Figure 3. Percent increases in student confidence from pre to post with technical engineering skills related to design and stakeholder needs and requirements.
Critical Reflections

Of the five reflection questions, the majority of the students chose to answer question 3, which asks how the course enhanced their academic experience, particularly in regards to what they learned about engineering and design. An open-coding approach was taken to identify emergent categories in question 3 since this had the highest student response rate.

**Table 3. Coding categories for reflection question 3.**

<table>
<thead>
<tr>
<th>Code</th>
<th>Example Response Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Solving</td>
<td>Problem solving, solve problems, problems, design problems</td>
</tr>
<tr>
<td>Iterative Design Process</td>
<td>Design process, engineering design process, changes, steps, trials, modify</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Team, teammates, group, others</td>
</tr>
<tr>
<td>Planning and Project Management</td>
<td>Plan, planning, think through, foresight, research, time, time management</td>
</tr>
<tr>
<td>Stakeholder Needs and Design</td>
<td>Requirements, specifications, design need, customer, consumer, client, client opinions, empathy, empathize, inclusion, including</td>
</tr>
<tr>
<td>Requirements</td>
<td></td>
</tr>
<tr>
<td>Prototype Testing</td>
<td>Prototype, prototyping, building, test, tested, trial and error</td>
</tr>
<tr>
<td>Engineering Mindset</td>
<td>Critical thinking, think, thinking differently, approach, behavior, resourceful, strategy</td>
</tr>
</tbody>
</table>

The most striking emergent category focused on identifying and understanding the stakeholder needs and design requirements. Figure 4 presents the frequency in which the different student participants listed this code in their reflection response. 46.4% of all the combined students involved in the service-learning courses indicated the importance of stakeholder needs and design requirements, compared to 4.5% of the students in the traditional courses. Apparent differences emerged among the female students, as 0% of the female students in the traditional courses did not mention anything in their response about considering stakeholder needs or design requirements while 50.0% of the female students in the service-learning course did. Some examples of student responses related to stakeholder needs and design requirements are provided below.

“Designing... for the customer is what is most important because as engineers we are working for the people of society and to improve their lives.”

“I learned that including your clientele in the design process is crucial. (It is) important because empathy... makes the project come out the way it should.”
“I learned that engineering and design is mostly customer based. There is no point in creating something if there is no one to use it. I learned this by reaching out to our customer to see what type of product she would be interested in, before we even began the design process. This project... required us to find a need and build around that.”

By participating in service learning, students had the opportunity to interact with real stakeholders (in this case, the respective elementary school staff and students) to design and modify their projects. The students applied engineering principles to solve real issues, while also developing valuable professional skills. In some cases, students reported that when they included others in the design process, they developed empathy. As the following response shows, working with and for others can extend far beyond the immediate service-learning experience.

“I learned... how to empathize with a client to find out exactly what they want out of a product. This... gave both my group partners and I a way of arriving at solutions through simple observations. With these skills, I intend to apply both empathy and observation in every single one of my future projects for the future.”

![Figure 4. Frequency of student reflection responses regarding what they learned about engineering and design (question 3) that fit into the stakeholder needs and design requirements code.](image-url)
Discussion and Recommendations

In general, this preliminary research indicates that first year engineering students who participate in service-learning courses report higher confidence gains in both technical and professional engineering skills when compared to students enrolled in traditional courses. The most noticeable impact was on female students who participated in service-learning courses. In particular, female first year engineering students who participated in a service-learning course showed the highest gains in confidence with both technical and professional engineering skills. These trends were consistent with regards to specific technical engineering skills involving identifying and understanding stakeholders needs and design requirements. The qualitative data correlates to these results and showed that the first year engineering students who participated in service-learning courses indicated that they learned about stakeholder needs and design requirements to a much higher degree than students who participated in a traditional course.

Although this study was limited to one cohort at LMU, the results are consistent with similar studies. Service-learning has significant potential to positively impact first-year engineering students, particularly female students. The first year engineering students who participated in service-learning courses felt much more confident with their technical engineering skillset. The higher gains in confidence can be attributed to the students learning more about how to identify and understand the stakeholder needs and design requirements.

Based on the results of this study, our general recommendations for other institutions looking to implement similar service-learning engineering projects include the following:

- Empathy is the first step. Ensure that the engineering students learn the importance of listening to the project stakeholders and understanding their needs.
- Inclusion is vital. Include the stakeholders in the design process as much as possible. Meet and interact with your stakeholders frequently.
- Identify a point of contact within your partnering organization for each student team. Have the students work directly with that point of contact.
- Plan to spend at least five years working with your community partner. Faculty advisors need to be dedicated and rewarded appropriately in terms of workload.

Acknowledgements

The authors would like to acknowledge Professor Rachel Adams and Professor Nazmul Ula for their support of distribution of the measurement instrument.

References

Appendix A: Engineering Design Self-Efficacy and Learning Outcomes Instrument

Rate your degree of confidence with each of the following items by recording a number from 0 to 100. (0 = low confidence, 50 = moderate confidence, 100 = high confidence).

Technical Engineering Skills
1. Design a system, component, or process to meet desired needs.
2. Identify a design need.
3. Understand the needs of the various project stakeholders (partners, customers, etc.).
4. Identify and establish design requirements and constraints.
5. Generate multiple design concept alternatives.
6. Apply scientific and engineering principles to analyze the performance of a design.
7. Construct design prototypes.
8. Design an experiment to test the performance of a design.
9. Conduct (or simulate) an experiment to test the design performance.
10. Analyze and interpret data.
11. Recommend and make appropriate design changes.
12. Apply techniques, skills, and modern engineering tools in practice (software, equipment, etc.).

Professional Skills
13. Communicate effectively with others.
14. Operate in the unknown (i.e., work on an open-ended design problem).
15. Involve various stakeholders in the design process.
16. Function effectively within a team.
17. Engage in critical, reliable, and valid self-assessment (i.e., reflection).
18. Persevere to complete an engineering design task.
19. Maintain a strong work ethic throughout an engineering design project.
20. Understand the impact of your design solution in a societal and global context.
21. Identify potential ethical issues and dilemmas of a project.
22. Understand the ethical responsibility associated with the engineering profession.
23. Recognize the need for life-long learning.
24. Knowing what you want to do after graduation (get a job, go to graduate school, etc.).

Instrument adapted from: Carberry et al. (2010), Pierrakos et al. (2007), and Pierrakos et al. (2008).
Appendix B: Critical Reflection Instrument

For two of the five areas below, critically reflect about what you have learned in that area from your engineering design project. Each reflection should address the following questions.

Guided questions for the reflection:
- What did I learn?
- How did I learn it?
- Why does this learning matter?
- What will/could others or I do in light of this learning?

Respond to 2 of the 5 items below:

1. Personal and Professional Development: What did you learn about who you are (your strengths, weaknesses, assumptions, skills, convictions, etc.) and who you want to become, personally or professionally?

2. Social Impact: What did you learn about the broader impacts of your work and how you and others can affect change locally and/or globally? What did you learn about the community, the needs, and/or the quality of the service provided?

3. Academic Enhancement: What did you learn about engineering and design? How did your engineering design project enhance your academic experience?

4. University Mission: How did this project align with the mission of the University? What aspects of the mission did you feel that your engineering design project resonated with?

5. Ethics: What you have learned about professional ethics, the ethical issues you encountered in your team and your project, and how decisions regarding ethical issues are made individually and as a team?

Instrument adapted from Ash et al. (2009)\textsuperscript{12}. 

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\textsuperscript{12} Ash et al. (2009)