

2006-824: LEARNING THROUGH SERVICE: ANALYSIS OF A FIRST COLLEGE WIDE SERVICE LEARNING COURSE

David Kazmer, University of Massachusetts-Lowell

David Kazmer is a Professor in the Department of Plastics Engineering at the University of Massachusetts Lowell. Prior to this position, Dave held various individual contributor and management positions at GE Plastics and Synventive Molding Solutions. He teaches and researches in the area of product design and manufacturing.

John Duffy, University of Massachusetts-Lowell

John Duffy is a Professor in the in the Department of Mechanical Engineering at the University of Massachusetts Lowell. He has an active interest in solar engineering and related technologies, which he has sought to implement through service-learning activities.

Beverly Perna, Tsongas Industrial History Center

Dr. Beverly Perna is the Museum Education Specialist at the Tsongas Industrial History Center where she oversees the development of science programming related to the Industrial Revolution. She acquired her interest in engineering in her ten years on the education staff of the Boston Museum of Science and has turned that interest into a variety of teachers' workshops, including one that examines the Pemberton Mill collapse in Lawrence, MA.

Learning through Service: Analysis of a First Semester, College-Wide, Service-Learning Course

1. Abstract

Service-learning is a pedagogy which strives to integrate student learning with community service. In an engineering context, service-learning provides a project-based experience in which students are confronted with real clients and problems, often of immediate need. In the context of course development, however, many engineering faculty seem to feel that service learning is infeasible in technical and/or large engineering courses, and that the overhead and opportunity costs associated with service learning exceed the benefits received by students.

This paper contemplates two years of service-learning integrated into a first engineering course with approximately three hundred students per year. The costs and benefits of service-learning to students, faculty, and clients are analyzed through several means including traditional teaching evaluations, blind pre- and post-assessments by students and clients, multi-year institutional data regarding student performance, and others. The results indicate that a majority of students personally believe that the described service-learning project is a valuable experience and should be integrated into engineering curriculum. However, the service-learning experience varied significantly between teams and students. Additional analysis and discussion indicates the underlying causality as well as significant impact on student motivation and success.

2. Introduction

Engineering education seems to have come under increased criticism lately, with many companies and students arguing that engineering curricula are too abstract and disconnected [1, 2]. It is interesting to reflect upon similar concerns of Henderson [3] and Grinter [4] dating back to 1983 and even 1955. These studies consistently indicate that engineering education should have the following properties:

1. Relevance to the lives and careers of students, preparing them for a broad range of careers, as well as for lifelong learning involving both formal programs and hands-on experience;
2. Attractiveness so that the excitement and intellectual content of engineering will attract highly talented students with a wider variety of backgrounds and career interests — particularly women, underrepresented minorities and the disabled — and will empower them to succeed; and
3. Connectedness to the needs and issues of the broader community through integrated activities with other parts of the educational system, industry and government.

One possible approach to providing relevance, attractiveness, and connectedness is service-learning. Service-learning is the integration of academic subject matter with service to the community in credit-bearing courses, with key elements including reciprocity, reflection, coaching, community voice in projects [5]. Service-learning has been shown to be effective in a large number of cognitive and affective measures, including critical thinking and tolerance for diversity, and leads to better knowledge of course subject matter, cooperative learning,

recruitment of under-represented groups in engineering, retention of students, and citizenship, as well as helping meet the well-known ABET 2000 criteria (a)-(k). A review of SL techniques is provided elsewhere [e.g., 5,6,7].

An underlying assumption of our current efforts is that SL spread throughout the core curriculum will be more effective than one intensive course, that a mixture of required and elective SL is more effective than either one or the other, and that SL could result in less coursework time than traditional programs satisfying ABET 2000 criteria. Therefore, service-learning is being integrated into a broad array of courses so that students will be exposed to SL in every semester in the core curriculum in all of our engineering departments. As part of this college-wide initiative, service-learning projects were incorporated into a first engineering course with approximately three hundred students.

The intent of this first engineering course design is to ensure competence in basic skills such as unit conversion while providing exposure to common business and human concerns that are common across all engineering disciplines, such as design methodology, engineering economics, ethics, and career development. To provide grounding of the course concepts, two design-build-test hardware projects were also implemented. It is hoped that the course will increase student's interest in engineering and thereby improve their likelihood of academic and career success [8].

3. Implementation

The lead author is a full professor, and has taught the introduction to engineering course in the fall semester from 2003 to 2005. The SL projects were implemented in 2004 and 2005, with changes made pursuant to student feedback and college initiatives. For instructional and research purposes, a more structured and conventional "design-build-test" project was also performed. Each of the project assignments will be briefly discussed prior to presentation and discussion of the results.

3.1 Rube Goldberg, First SL Project, Fall 2004

The client for both SL projects was a regional industrial history center which is a part of the United States National Park Service. The museum annually hosts approximately 50,000 students from the ages of 9 to 16 to investigate the history and technology of the American Industrial Revolution where it first occurred in the United States as a large-scale enterprise. Through guided tours of National Park historic sites, students "do history" by weaving, creating a canal system and testing water wheels, working on an assembly line, role-playing immigrants, or becoming inventors. In investigating industrial history, students can also "do science" by testing river or canal water quality, tracing the flow of groundwater pollution, or discovering river cleanup techniques.

The first SL project was motivated by cartoonist Reuben Lucius Goldberg. For 55 years Goldberg's award-winning cartoons satirized machines and gadgets which he saw as excessive. His cartoons combined simple machines and common household items to create complex, wacky, and diabolically logical machines that accomplished mundane and trivial tasks. His inventions became so widely known that Webster's Dictionary added "rube goldberg" to its

listing, defining it as “accomplishing by extremely complex, roundabout means what seemingly could be done simply.”

The client specifically requested assistance in the development of an interactive workshop-exhibit titled the “Inventions Workshop.” The subject of the exhibit was the product development process, and strived to have student-visitors develop innovative solutions in a 90-minute workshop. The first SL project was structured to engage students in creating hands-on interactive exhibits that demonstrate various engineering principles in interesting ways; related presentation materials would show how the team progressed from the problem assignment to the final solution. Accordingly, the client hoped that the exhibit would orient student-visitors to careers in engineering.

The project assignment was provided in a seven page specification along with two worksheets. The first worksheet focused on concept design, and included a decision table evaluating different concepts with respect to:

- theme,
- creative use of materials,
- innovative operation,
- robustness,
- and other performance measures.

The second worksheet focused on detailed design and implementation, and included a score sheet for the judges to evaluate the final projects according to the same performance measures used for concept design. The project grade constituted 15% of the course grade, and was determined according to peer evaluation (20%), concept design and selection (20%), development process (20%), final design documentation (20%), and project evaluation by the client staff (40%). The client’s evaluations of the projects were performed in a rapid fire mode during which approximately 100 student projects were presented during two hours of scheduled lecture time. The best five projects were installed at a museum exhibition six weeks after the project completion and remained on display for viewing by 50,000 visitors in 2005. An introductory exhibit panel provided information about Rube Goldberg and the steps in the engineering design and product development process.

3.2 Technology Exhibition, Second SL Project, Fall 2005

The second SL project was motivated by the history of engineering technology, especially as it pertains to the history and future of local industry. In this project, the students were asked to bring relevant engineering technologies to life through the development of hands-on and informative exhibits. While the objective of the Rube Goldberg project was to demonstrate the design process for a targeted workshop, the objective of the Technology Exhibition project was to provide an array of self-guided exhibits that could be located throughout the museum (e.g. lunchroom, lobbies, etc.) to occupy and delight visitors during what would otherwise be down-time.

The project assignment was provided in a nine page specification along with two worksheets. The specification included a description of two prominent local inventors that are highlighted in the museum, as well as a list of about a hundred significant engineering technologies that were abstracted from the course text book. The worksheets were similar to those provided for the first

project, and were intended to direct the student teams from concept development through implementation.

To improve the significance and quality of the SL project, the weighting of the project was increased from 15% of the course grade in 2004 to 25% of the course grade in 2005. To motivate students to meet with the client and proactively work on the projects, students also received bonuses equivalent to 1% of the course grade for attending client open houses and other client-related events. The project grade was determined according to concept design and selection (30%), final design documentation (20%), an eight minute project presentation (20%), and project evaluation by the client staff (30%). The client evaluated the project according to relevance to audience, relevance to museum, creativity, difficulty, and reliability. All projects were first presented in smaller lab sections of averaging 25 students, with semi-finalists selected by one member of the client staff. Twenty four semi-finalists then presented their projects to three members of the client staff during the scheduled two hour lecture session. Twelve finalists were immediately selected and their projects installed at an exhibition and reception later that evening.

3.3 Bridge Design, Conventional Project, Fall 2003, 2004, and 2005

In all offerings of the course, a bridge design contest was conducted. The objective was to introduce students to team projects, design-build-test cycles, and quantitative performance measurement. The Bridge Design project constituted 15% of the course grade, and was evaluated according to concept design (30%), detailed design (30%), and bridge performance (40%). The bridge performance measure was explicitly defined according to the formula:

$$Grade = 100 - 5000 / \frac{Load}{Weight} - 10 \times Failure$$

where *Grade* is the performance of the bridge evaluated during class, worth 40% of this project, *Load* is the maximum load (measured in grams force) that was carried during testing to a maximum of 50 lbs (22500 grams), *Weight* is the weight of the bridge measure in grams force, and *Failure* is evaluated as 1 if the bridge failed and 0 if the bridge did not fail. The objective of this performance measurement was to introduce students to the concepts of design efficiency (defined by the load to weight ratio of the bridge) as well as risk (defined as the failure of the bridge to carry a specified 50 pound load). For reference, the best load to weight ratio without failure was ~2000:1. All projects were tested with a uniaxial testing apparatus including appropriate instrumentation during a two hour lecture session.

4. Results

4.1 Client Satisfaction

In both SL projects, the client had a major role in structuring the projects, evaluating the student performance, and using the resulting exhibits. It is noted that in these SL projects, the client is required to devote significant resources to recoup unknown benefits. As with any museum development activity, a cost:benefit analysis was evaluated on the SL project with favorable results. One client representative/park service employee indicated that one of the student projects, shown below in Figure 1, was of professional quality and would have cost \$5,000 to \$10,000 if provided by a supplier under contract.

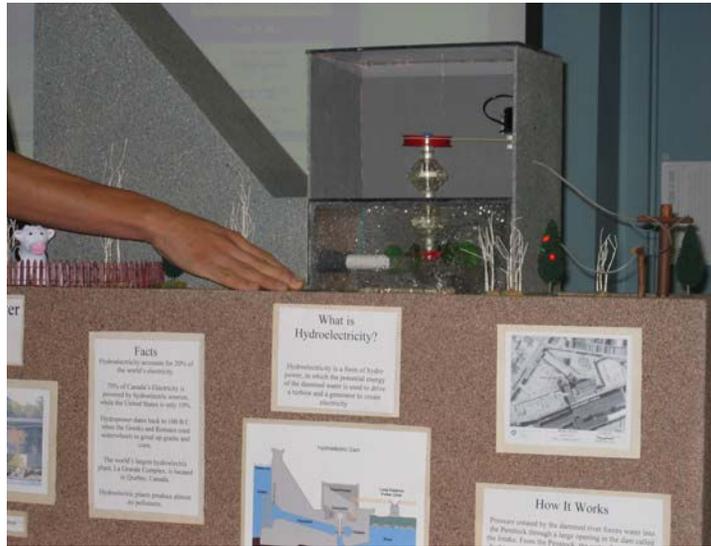


Figure 1: Grand Champion of Technology Exhibition

After both SL projects, a debriefing was conducted with the client; the client director and staff indicated that they enjoyed working on the project[s]. Some written comments from the director and primary liaison, respectively, are provided in Appendices A.1 and A.2. Perhaps the single best measure of client satisfaction is their continued commitment from the first to the second project, as well as their documented interest in a third project next year through “institutionalization.” Accordingly, the SL project can bring significant benefits to the client, although it requires significant commitment on the part of the client, faculty, and students.

4.2 Academic Performance

Across all three years that the instructor has taught the course, the course content and grading system has remained essentially the same. Each year, the hardware projects comprised 40% of the course grade with homework assignments, quizzes, and a test constituting the remainder. In 2003, no SL project was utilized; the mean course grade and standard deviation across all students were, respectively, 67.9% and 24.5%. In 2004, the first SL project was incorporated and the observed mean and standard deviation were 76.3% and 27.9%. In 2005, the second SL project was incorporated and the observed mean and standard deviation were 77.3% and 18.9%. For reference, in each of the years that the course has been taught by this instructor, at least one student earned a final grade above 99.9%. The data across all three offerings of the course indicates that the inclusion of the SL projects may have resulted in improved academic performance.

There is no stated policy for distribution of grades at the host institution. In assigning final letter grades, the instructor rank ordered all students and examined the distribution for gaps between populations to differentiate students earning an “A” from those earning a “B”. The resulting distribution of grades is shown in Figure 2. It is see that from 2003 to 2005, there is a clear mean shift from “F”s to “A”s, even though the course grading was not relaxed. Indeed, the course was graded more strictly. The cut-off between “D” and “F” was set to a lenient 20% in 2003 and a slightly more stringent 25% in 2005. Similarly, the cut-off between a “C” and a “D” was increased from 45% in 2003 to 50% in 2005.

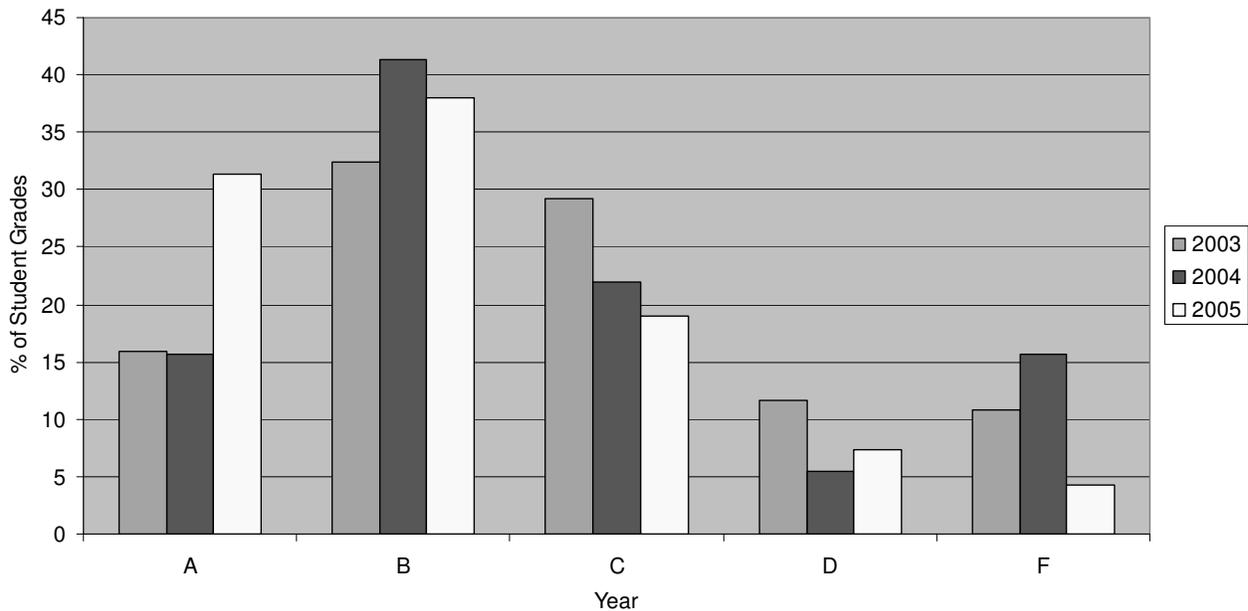


Figure 2: Course Final Grade Distributions for 2003 to 2005

The reduced number of “D” and “F” students from 2003 to 2005, concurrent with the more stringent grading policies, is a significant indicator that students are more motivated and demonstrate a better command of the course material. This data, however, does not resolve the confounding of the year to year improvement in instructor performance with the addition of the SL projects. Accordingly, student self-assessment of the projects is next presented.

4.3 Student Self-Assessment

Self assessments were conducted by the students before and after completion of both the SL projects. Some statistics about the students in the course during the Fall of 2005 (second year) are provided in Table 1. The host institution is an urban public University, with a significant proportion of commuting and working students.

Table 1: Statistical Profile of Students

Statistic (n = 440)	Mean	Median
Age	18.6	18
Sex (% Male)	90%	N/A
Ethnicity (% Caucasian)	76%	N/A
Employment (Hours/Week)	13.0	14
Course Load (Registered Credit Hours)	13.4	14
Commuting Distance (Miles)	17.7	10

Students were asked the extent to which they agreed or disagreed to a number of questions on a 1 to 9 point scale. The resulting data is ordinal in nature, and histograms were created and analyzed as part of the assessment process. As a summary of this analysis, statistical averages and standard deviations were computed and are presented as representative of the responses. The

questions as posed to the students and the statistical results from the first SL project (Rube Goldberg) are provided in Figure 3.

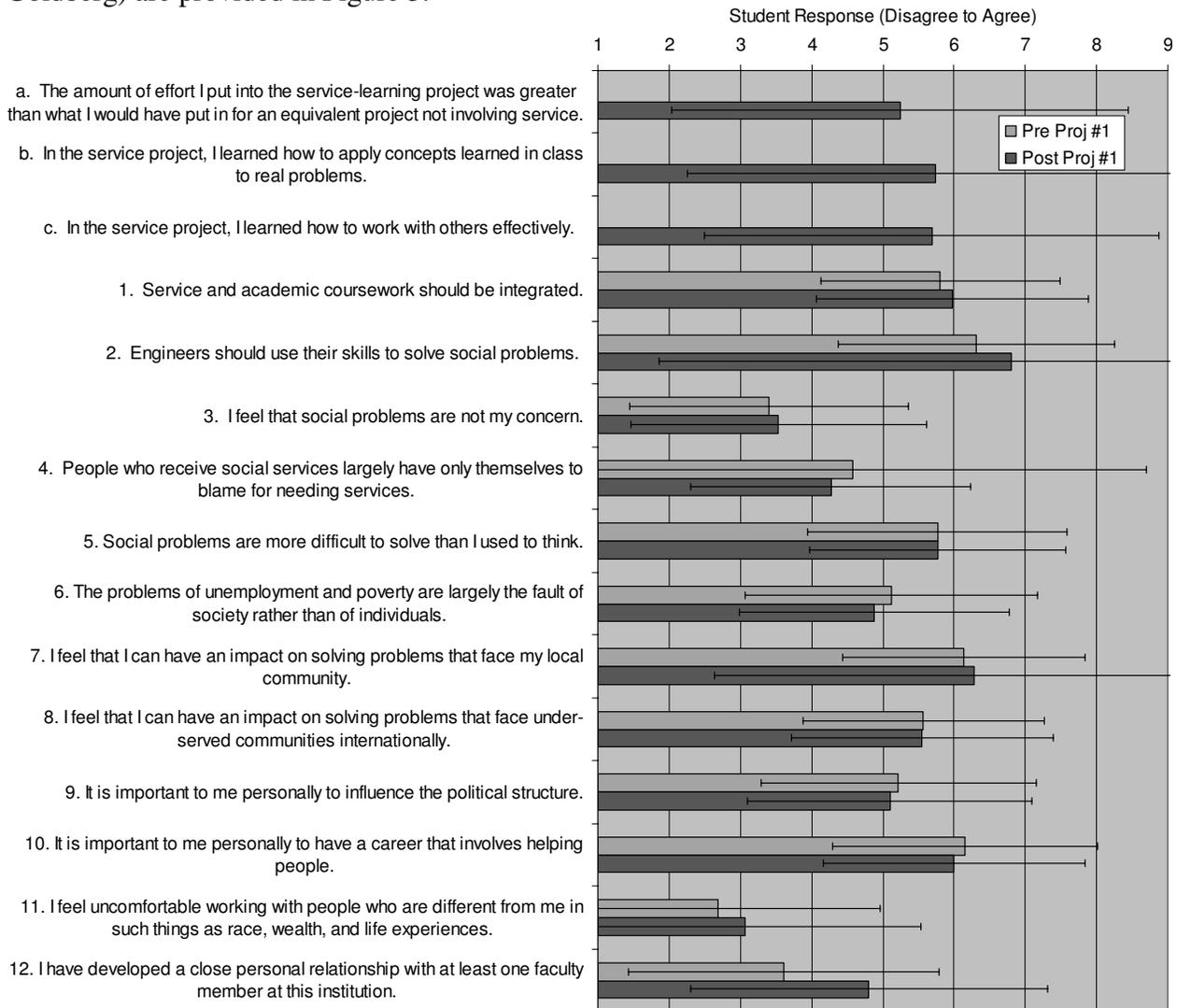


Figure 3: Pre and post self-assessment for the 2004 SL project (Rube Goldberg)

The first three questions, identified as (a) to (c), addressed the effort and outcome related to the project. A result of 5 indicates that the students were indifferent to the question and/or the fraction of the class agreeing with the question equaled the fraction disagreeing with the question. It is observed that the students overall slightly agreed that (a) they put more effort into the SL project, but the variance across the student body was significant. Students similarly agreed that they learned (b) how to apply class concept to real problems and (c) how to effectively work with others in the first SL project.

The remaining twelve questions assess the social outcomes associated with the first SL project. The first two questions investigated the role of service in academic coursework and engineering practice. Students generally agreed both before and after the project that service and academic coursework should be integrated. Students also agreed that engineers should use their skills to solve social problems. While student sentiment about the role of engineers to solve social

problems slightly increased after the SL project, the range of the responses increased significantly.

Questions 3 and 4 addressed the ownership of social problems. Students generally felt that social problems are not their concern, with no significant change across the student body after the first SL project. Before the SL project, students were indifferent with respect to who is to blame for social problems. After the project, there was a slight change in the mean response, but a very significant narrowing of student opinion.

Questions 5 to 10 investigated the student's role in solving social problems. The students generally recognized that social problems are complex and difficult to solve, but that they could individually have an impact on the local level. Students were not as positive about changing the political structure or solving social problems on an international scale. Students did indicate that it is personally important to have a career that helps people. The mean and standard deviation of the responses to these particular questions did not change significantly before and after the project.

Questions 11 and 12 assessed the relationships between the student and other people. Students generally indicated that they did not feel uncomfortable working with people of different race or background, though more discomfort was acknowledged after the SL project. With respect to the faculty relations, a greater number of students after the project than before the project indicated that they felt a close personal relationship with a faculty member at the University.

Similar pre- and post-assessments were conducted for the second SL project (Technology Exhibition) conducted in the Fall of 2005, and are provided in Figure 4. The first three questions, identified as (a) to (c), addressed the effort and outcome related to the project. It is again observed that the students overall slightly agreed that (a) they put more effort into the SL project. Interestingly, students agreed more positively that they learned (b) how to apply class concept to real problems and (c) how to effectively work with others in the first SL project. This improved result may be due to the positioning of the unstructured Technology Exhibition project after the structure Bridge Design project.

The remaining twelve questions assess the social outcomes associated with the first SL project. Most of the student responses were very similar to the previous years:

- Questions 3 and 4 addressed the ownership of social problems, and revealed that students generally felt that social problems are not their concern.
- Questions 5 to 10 investigated the student's role in solving social problems, and indicated that students generally recognized that social problems are complex and difficult to solve, but that they could individually have an impact on the local level.
- Questions 11 and 12 assessed the relationships between the student and other people. Students again indicated that they did not feel uncomfortable working with people of different race or background, and in 2005 there was less discomfort acknowledged after the SL project. With respect to the faculty relations, a greater number of students after the project than before the project again indicated that they felt a close personal relationship with a faculty member at the University.

A paired-t test was performed on the 2005 data for 100 responses that had ID numbers entered on the “pre” and “post” surveys that could be matched. At the 5% level, there was a significant difference in the average level of agreement on questions 1, 2, 3, 8, 9, 10, and 12. All the mean changes in responses were in the positive direction pre to post, except the responses to question 3; that is, all were in the direction one would expect in terms of improvement.

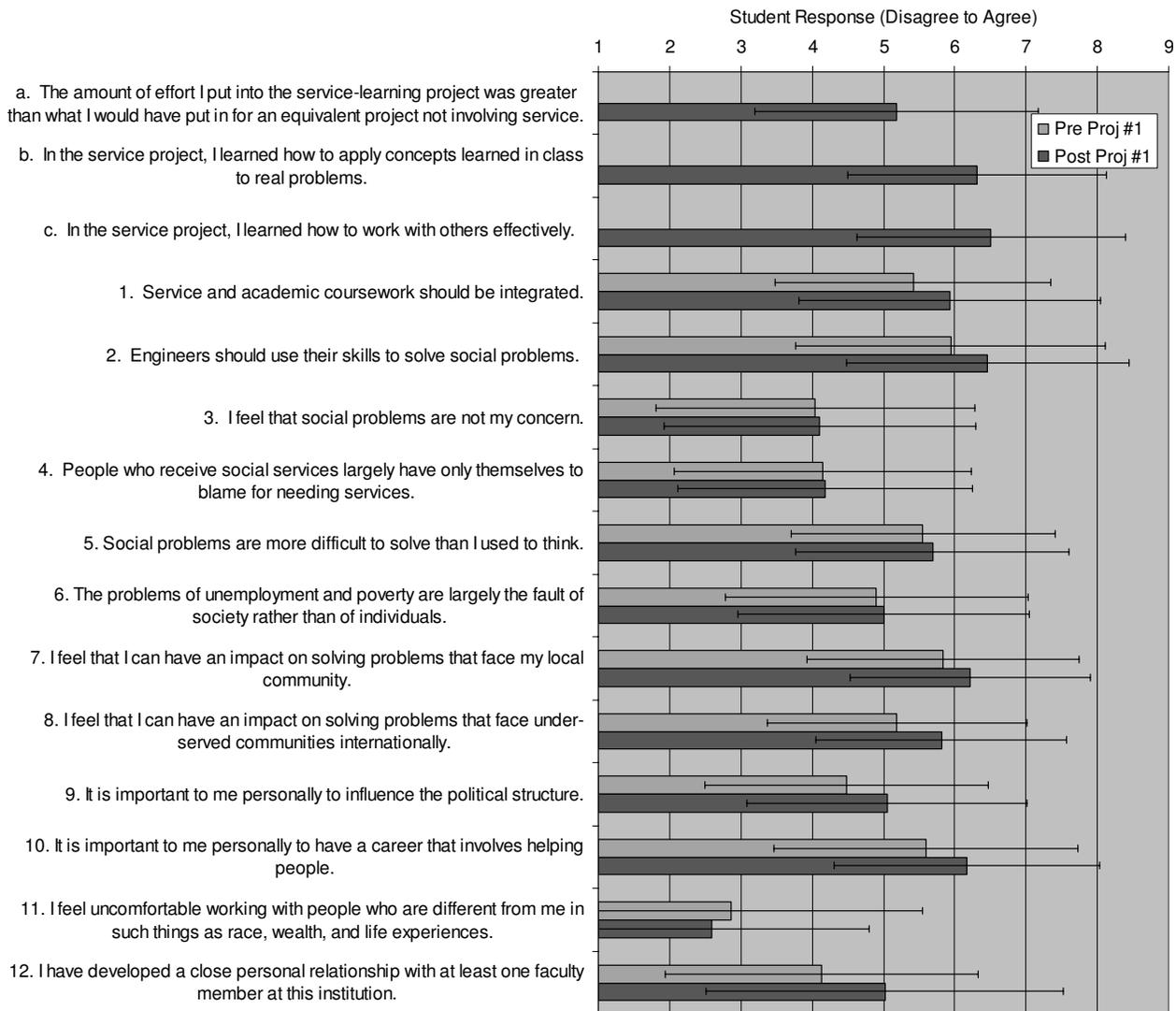


Figure 4: Pre and post self-assessment for the second SL project (Technology Exhibition)

While there are many differences between the results of the Rube Goldberg project in 2004 and the Technology Exhibition project in 2005, perhaps the most significant results are that students:

- felt (questions 7 and 8) that they could more positively influence the community (questions 7 to 9);
- recognized the importance of helping others in their career (question 10); and
- were more comfortable working with a diversity of people (question 11).

5. Discussion

5.1 SL Comparison to Conventional Teaching Methods

A fundamental tenet of many engineering educators is that students learn by reflecting on their physical experiences and by linking and contextualizing theoretical to practical knowledge [9]. Fundamental engineering concepts such as energy, momentum, and torque are frequently used in engineering education and practice. However, a large body of research in physics learning shows that students have difficulty connecting abstract concepts to their experiential understanding [10]. For these reasons, the design-build-test projects have been incorporated into the first engineering course to complement traditional lectures.

Student evaluations of teaching quantified and describe the importance to them of the course projects. Figure 5 provides the distribution of students who believed that the bridge and SL projects were valuable experiences. To summarize these results, 89% of students agreed or strongly agreed that the bridge project was a valuable experience while 76% of students agreed or strongly agreed that the SL project was a valuable experience.

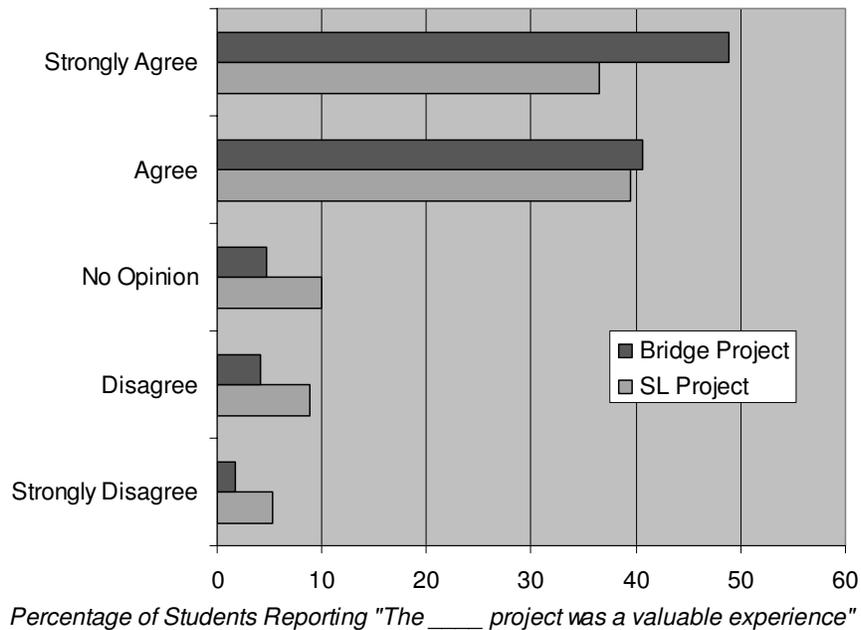


Figure 5: Comparison of SL and non-SL project value as perceived by students

All the students' reported comments about the most recent year's projects (with the bridge project and the Technology Exhibition SL project) are provided in Appendix B. In general, the perception of the students varied more widely for the SL project than for the bridge project. The comments of Appendix B.1 indicate that the projects were helpful, fun, and/or valuable. The bridge project was very structured since all materials were provided to the student teams and the performance measurement was explicitly defined and measurable to an accuracy of 0.1%. The written comments and results of Figure 5 indicate that the project successfully provided students insights into team work, design strategy, and project management.

By comparison, the SL project was mostly unstructured since no materials were provided to the student teams and the performance was measured by the client. Because of its unstructured but “real” nature, the SL project provided the students significant insights into problem definition, concept design, and client management. These abilities are of great importance to engineers yet difficult to teach in traditional engineering courses [11].

Alas, the results of Figure 5 and the comments of Appendix B.2 and B.3 indicate that there was greater variance in the amount of perceived learning in the SL project than in the bridge project. Students indicated by the comments in Appendix B.2 that there was a lack of resources, including money, fabrication facilities, and instructor time; these significant issues can not be easily addressed without changing the infrastructure of the host institution. The comments of Appendix B.3 indicate that the subject matter of the SL project was both too undefined and too constricting for students. Students suggested that the grounds for evaluation were not well enough defined, and that some very good projects received a lower grade than poorer projects that were selected for exhibition by the client.

These student criticisms are not easily addressed since no single client can provide a project of sufficient breadth to support all engineering majors and interests. In the future, we plan to solve these problems by agreeing that the theme would be “inventions of historical significance” and training our judges to accept and exhibit the best explanatory/demonstration exhibits regardless of whether they addressed the client’s themes and teaching objectives. Alternatively, or in addition, we are considering adding the College of Engineering itself as an SL client for students to develop exhibits that showcase engineering for use during tours and open houses.

In the context of this first engineering course, however, the SL projects have had two primary advantages compared to more conventional, well-defined projects. First, the SL projects have been largely unstructured and mostly open ended, allowing the students to define how best to satisfy the client’s need and develop the hardware and related materials. Understanding how to define the requirements, structure the project, and implement the design in a multi-person team are critical skills that have been well developed through the use of the SL projects in this course. As part of the ABET accreditation process, students in the course were specifically asked whether they could function in multi-person teams, and perform typical design/build/test projects. The results are provided in Figure 6.

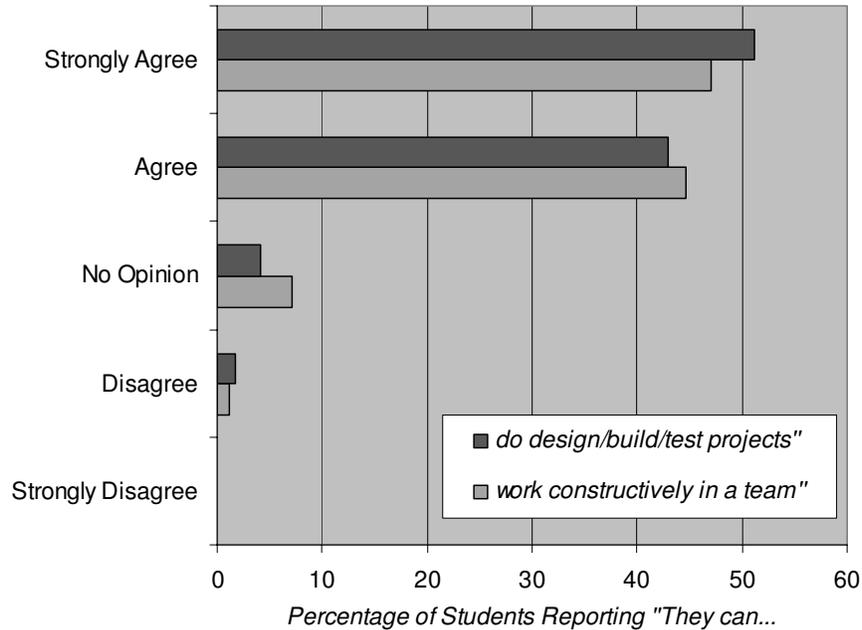


Figure 6: Student self-assessment of project skills

While no pre-assessment was performed with regard to these questions, it is our belief that the implementation of both a structured and an unstructured project provided students a true introduction to engineering, and excellent preparation for later engineering coursework and practice.

The second advantage of the SL projects is that the client’s real need, along with their staff evaluating the project performance, clearly provided motivation for many of the students to produce high quality designs. Related to this was the removal of the instructor as the primary evaluator, which had the unexpected benefit of the instructor becoming an advocate rather than a critic for the students.

5.2 Workload Issues

There is a heavy workload required to deliver a first engineering course to three hundred students, even without any hardware projects. The bridge project required approximately twenty hours to plan and implement for the instructor. For the first SL project (Rube Goldberg), approximately forty hours in total were spent planning the project with the client, developing the assignment, managing the student projects, evaluating the projects, and supporting the installation of the projects. For the second SL project (Technology Exhibition), the workload was approximately one hundred hours. This higher workload was due to the inclusion of 15 hours of project presentations, along with additional time spent with students working on their projects. It is interesting to reflect that these projects could be replaced with two lectures and two homework assignments, with a lower teaching load but different learning outcomes.

In addition to the time requirements, there is a significant increase in stress and apparent workload from the expectations from the client and the larger community that the SL projects will be a success. For all these reasons, the instructor reports feeling “burnt out” after the completion of the projects. Possible reductions in workload may be achieved through the

addition of the engineering workshop and technical laboratory instructor, additional training and earlier recruitment of teaching assistants to enable them to provide more guidance to students in the labs, and possibly integrating juniors/seniors to mentor first-year students. However, all such tactics require substantial changes to the existing infrastructure and curriculum.

5.3 Best Practices & Future Plans

In retrospect, the first SL project had to be developed fairly quickly, and was not perceived to be as great a success as the second project by the client or the instructional team. The improved results in the second SL project were largely due to changes in the course and project structure after reflecting on the first SL project. The following best practices have evolved with respect to implementing a SL project:

- *Listen.* Based on comments from students, the second SL project 1) was performed after the students gained some experience with the bridge project, 2) had its subject matter broadened from the first year, and 3) utilized a client “open house” for students to meet with the client. Based on the most recent student comments in the second year, the SL project in year three will at least 1) have even more diverse subject matter, 2) have better defined performance measures, and 3) provide for more interaction with the client and instruction team before project delivery.
- *Bond.* In these SL projects, there was significant client-side pull. The client’s commitment was vital to being able to 1) meet at will to jointly define the project, 2) have the client evaluate the project performance, and 3) have the client actually use the project deliverables. Without such client-side leadership, it is uncertain if the SL projects would be as real or engaging.
- *Formalize.* In the first SL project, the hardware and supporting project were due at the end of the project. Even though students had time to work in lab sections with the help of teaching assistants, many students fell behind and ended up cramming the project. To alleviate this issue, the second SL project was broken into smaller milestones corresponding to concept development, layout design, and hardware testing. Even so, many students did not meet the deadlines and this problem was compounded by a lenient late-grade policy. In the future, project milestones will be made more formal by requiring student presentations of the required deliverables in lab sections.
- *Simplify.* Some students indicated that they were not given sufficient instructions and the project needed to be better defined, even though many of these same students admitted that they had not read the specifications or worksheets. For this reason, in the future, the projects will be simplified to require fewer deliverables that are more easily understood and better emphasized. It is likely that the nine page specification and four pages of worksheets will be provided in a more modular format, with each project consisting of three kits including two pages of description and a one page worksheet.
- *Celebrate.* In both years, the client sponsored a reception at the end of the course for all first-year students at which certificates were presented to teams whose projects were selected for exhibition and at which the course instructor and client made brief remarks and expressed appreciation. Pizza and soft drinks were provided. In both years, approximately one-third of the students attended the reception/exhibition. In the second year, the reception was held in a larger client space with tables, which increased the amount of student-student and student-client interaction. In the assessment of both the client and the instructional team, the projects in year two were of demonstrably higher

quality than the projects in year 1, which, in turn, enabled the Dean of the College of Engineering, the Client and the Instructor to provide more enthusiastic and meaningful praise. The University's public relations staff was involved earlier in publicizing the project in the University magazine. In the future, as service-learning projects are integrated into all levels of our engineering program, it is possible to expand the partnership with the client so that engineering students can not only exhibit their projects, but also sustain their involvement by taking on higher-level projects that are exhibited for longer periods, volunteering as "explainers" for the client as part of scheduled special events, and other collaborative relationships.

6. Conclusions

Service-learning has been used as an effective instructional method in an introductory engineering course required of all incoming students. The results indicate that a majority of students believe that the implemented service-learning project was a valuable experience, and that service-learning should be incorporated into other engineering courses. Compared with a conventional design/build/test project, students were 1) more challenged by the unstructured nature of the project, and 2) more motivated by the needs of "real" end-users and evaluation by a "real" client. While the implemented service-learning projects require added effort and entail added risk, we have found that the benefits outweigh these costs.

7. Acknowledgements

This paper was funded in part by the Engineering Education Program of the National Science foundation, Grants EEC-0431925 and EEC-0530632. This paper does not reflect the opinions of the National Science Foundation or the United States government.

8. Bibliography

1. Green, H., *Engineering Education for a Changing World*. 1994, American Society of Engineering Education.
2. McMasters, J.H. and L.A. Matsch. *Desired Attributes of an Engineering Graduate - An Industry Perspective*. in *19th AIAA Advanced Measurement and Ground Testing Technology Conference*. 1996. New Orleans, LA.
3. Henderson, J.M., L.E. Bellman, and B.J. Furman, *A Case for Teaching Engineering with Cases*. *Engineering Education*, 1983(1): p. 1.
4. Grinter, L.E., *Summary of the Report on Evaluation of Engineering Education*. *Journal of Engineering Education*, 1955(9): p. 25-60.
5. Jacoby, B., *Service Learning in Higher Education*. 1996, San Francisco: Jossey-Bass.
6. Tsang, E., (ed.), 2000, *Projects that Matter: Concepts and Models for Service-Learning in Engineering*, American Association of Higher Education, Washington, DC.
7. Oakes, W., 2004, *Service-Learning in Engineering: A Resource Guidebook*, Campus Compact, Providence, RI, URL http://www.compact.org/publication/SL_and_Engineering-WEB.pdf
8. Kazmer, D.O. *Declaring an Engineering Major: By Choice or by Chance?* in *ASEE Northeast Regional Meeting*. 2004. Boston, MA.
9. Brereton, M., S. Sheppard, and L. Leifer. *Students Connecting Engineering Fundamental and Hardware Design: Observations and Implications for the Design of Curriculum and Assessment Methods*. in *1995 Frontiers in Education Conference*. 1995. Atlanta, GA.
10. DiSessa, A.A., *Toward an Epistemology of Physics*. *Cognition Instruction*, 1993. **10**(2): p. 3.
11. Andrews, J.G., *In Search of the Engineering Method*. *Engineering Education*, 1987. **78**(1): p. 29-30, 55-57.

Appendix A: Comments of SL Client

A.1 Comments of Client Director

- [The SL] project was a tremendous success. Collaborations like this are complex and usually take at least three times or more to iron out the kinks and to achieve the quality of the work we saw from the students last night.... The credit goes to you [the instructor] because of the thoughtfulness of your analysis of last year's student evaluations and the comments of your engineering faculty colleagues, the thoroughness of your preparation and follow-through, and your full commitment to creating this kind of real-world experience as part of the students' first engineering course. You structured our work as the client so it was very straight-forward, we knew our roles, we had flexibility in which staff we could assign as judges, and the reception could go well. Adding the 'consultation with the client' activity in which students visited the Tsongas Center in advance of their projects worked very well. It helped them understand the audience for which they would be designing their projects, which was reflected in many of the winning projects. Also, I suspect students know and appreciate [the] significance in the history of technology.
- We should ... (1) capture the conversations we had at the project fair/reception, (2) discuss how best to develop graphics to go with the exhibits of the student work to acknowledge the College of Engineering, the NSF funding role, and the work of the individual student teams; (3) capture the insights about how an excellent program might be 'institutionalized' in both organizations; (4) determine whether we should provide some training for your TAs in advance of next year's projects to reduce your work load, (5) reflect a bit more about how we could turn the exhibition/fair into a somewhat more public event (more NPS and Tsongas Center staff in attendance, perhaps invite the engineering sophomores to attend, whether we would/should seek corporate representatives to attend, (6) capture for the National Park the hours you and the students spent as 'park volunteers' and in turn, think about ways that the Park might recognize the students whose projects were selected for display; and (7) think about whether there is a way to provide a next level of experience for some of these students at the Park or Tsongas Center.

A.2 Comments of Client's Primary Liaison

- I have to say that this project with you is one of the more satisfying things I am involved with during the course of the year. I know it is a tremendous load for you [the instructor], but the results are impressive! I still wish we could have taken more of them. The sprinkler system was awesome, and I wish I could have seen the laser project. It was clear that many more [students] took the challenge and ran with it this year.

Appendix B: Student Comments

B.1 Positive Comments about Projects

- The course was very helpful and the projects were very fun to do.
- I felt that this project was a fun and great learning process of the ideas that we chose.
- It was a valuable experience because it enlightened many students and people at the exhibition. It also brought out the best in students' abilities.

- I would suggest having even more projects. The design process and the learning to work in groups is definitely a valuable experience.
- The projects were fun and they helped my understanding of what being an engineer is all about.
- The SL project, and Prof. X's experience as an engineer were fulfilling.
- The bridge project was a great idea. It made us think and decide which structures would be able to hold the weight. It also had us conserve the supplies and work in groups.
- The SL project was very good to develop skills.
- I feel the projects help me interact with other people and is a good preparation for what I will be seeing in a real work environment.
- Keep doing the same projects next year.
- Continue to do both projects. They are very helpful and fun.
- The good thing about the bridge project was that although everyone was given the same things to make the bridge out of the constrictions of the project required everyone to make the best design possible.

B.2 Comments Indicating a Lack of Resources or Directions

- I felt that the teacher did not give us enough resources to build our project.
- The two projects may have been a bit too much for an Intro. Class
- Remove the need to have a partner for the SL project. My partner was didn't help out too much on the project and that made it really hard for me to complete.
- This class was my most demanding class this semester. As a chemical engineering student I felt the bridge project was unnecessary.
- Give more specific requirements for the SL Project. Our group was unsure about the level of sophistication needed for the hardware in order to earn a good grade.
- I think removing a couple of the homeworks and replacing them with another project could be a good idea.
- Group projects are hard mainly for commuter students.
- He did not present any means of going or setting up access to a shop room so that we could manufacture this project.
- The projects I suppose were an example of real practice, but resources and time were very limited and we could not put as much as we wanted to into it.
- I think that there should be more interaction between students and teachers during project construction, especially on project #2, Professor X should see the projects before they are done.
- I think there should be a limit on how much can be spent on a project. Some teams spent way to much money.

B.3 Comments Indicating Biasing of the SL Project

- The problem with the SL project is that it is too broad. It needs to been narrowed down so students don't run themselves into a corner.
- I lost interest in the course after I learned the second project would be an exhibit. I thoroughly enjoyed the bridge project and I feel a competitive project similar but non-civil one should have been the second project

- The SL project was not an adequate use of a project. I recall Professor X discussing a project on hybrid vehicles in the course introduction, I was looking forward to this project and was very disappointed that so much of my project 2 was determined by the museum rather than an engineering curriculum.
- When we choose our own project it's a great idea but it has some side effects too. We would sometimes be not able to limit the scope of the project. I recommend that the instructor lets the students know about the grounds of evaluation of the project like in the bridge project, may be not that brief.
- I would suggest that we did something more like the bridge project where something is designed and tested with a possible retesting after correcting problems. The museum project was a waste of time because(if done according to the outline, which stated that the project should be related to the history of Y) it was more like doing a study on the history of Y and making a primitive device that generated power. If this type of project is to be continued to the future I would recommend that you open up the list of topics to everything, since there are much more interesting things in the world of engineering. Just my 2 cents.
- The SL project wasn't appreciated to all for what was put into it. Only the projects that appealed to the judges moved on even if they were good.
- My only suggestion is that the description on what the museum expects to see should be made more clear. Many good projects do not make it to the second round because they are not highly related to the museum's theme. Even though they are very good projects.
- Change Project #2, it seemed biased.
- Legos should be banned from use on project 2. The world is not constructed with colored, pre-fit, easy-to-assemble blocks. The use of legos was an insult to all teams that built projects from scratch.

B.4 Negative Comments about Projects

- I would remove the SL project. It does not demonstrate any thing productive and is more like a freshman high school physics project.
- The bridge project should be removed. It made me feel sort of offended. I thought I was supposed to be in college then all of a sudden I have the same project that my mom does with her 3 year old daycare kids.