Using a model-building task to compare the design process of service learning and non-service learning engineering students

Gay Lemons
Tufts University, Medford, MA, USA
gay.lemons@tufts.edu

Adam Carberry
Tufts University, Medford, MA, USA
adam.carberry@tufts.edu

Chris Rogers
Tufts University, Medford, MA, USA
chris.rogers@tufts.edu

Chris Swan
Tufts University, Medford, MA, USA
chris.swan@tufts.ed

Linda Jarvin
Tufts University, Medford, MA, USA
Linda.jarvin@tufts.edu

***Abstract**: Verbal protocol analysis was employed during a task in which engineering students were asked to design and construct a prototype jar opener for physically challenged individuals. Differences in the design process were observed between students involved in a service learning (SL) program and students not involved in a program. The SL students appeared more skilled in being able to discriminate between useful and insignificant information and were able to frame the problem more quickly, than students not involved in SL programs. Gender differences were also found. The men appeared more conscious of their model building skills, referring to the materials an average of 15 times; the women an average of 2 times. The women were more client focused, referring to the client an average of 17 times; the men an average of 8 times. That the women were client focused may help explain why women are drawn to SL programs that incorporate community needs.*

Introduction

Service Learning

Engineering schools have recognized the benefits of service learning as a pedagogical tool. Service learning (SL) has been defined as an activity that integrates academic subject matter with service to community that helps foster civic responsibility (Barrington & Duffy, 2007; Coyle, Jamison & Oakes, 2005). Engineering SL programs produce a functional product that satisfies the needs of the community partner while offering 'real life' experiences to engineering students.

An added benefit of SL programs is that they tend to have a higher percentage of women participants in relation to the percentage of women in engineering overall. For example, at Purdue University, which has an Engineering Projects in Community Service (EPICS) program, the percent of women in the Electrical and Computer Engineering (ECE) and Mechanical Engineering (ME) programs range between 10% and 12%, while 20% of students involved in EPICS are women (Matusovich, Follman, & Oakes, 2006). At the University of Massachusetts-Lowell, 12.5% of their engineering undergraduates are women, but on a SL trip to Peru, 38% of the students were women (Barrington & Duffy, 2007). At Tufts University, 30% (which is unusually high) of their engineering undergraduates are women however, about 60% of students participating in their Student Teacher Outreach Mentorship Program (STOMP) are women.

Understanding why women are drawn to SL programs can offer insight regarding how to remedy the critical under-representation of women in Science, Technology, Engineering and Math (STEM) disciplines. But before we can understand why women are attracted to SL programs, we first need to investigate and compare the perspectives and design processes between students involved in SL activities to students not involved in SL activities. This research was driven by the following questions:

1. Do SL students differ from non-SL students in their approach to the engineering design process?
2. Why do SL programs tend to attract a disproportionate number of women in relation to the overall number of women in engineering programs?

Theoretical Background

Gender Identity Theory

The low number of women in STEM programs can be explained in part by Gender Identity Theory. According to Chodrow (1974), gender identity formation is different for boys and girls because mothers, who are universally largely responsible for early childcare, experience their daughters as more like and continuous with themselves, and experience their sons as male opposites. In identifying themselves as female, girls fuse their identity formation with attachment and emerge with a sense of empathy built into their definition of self. In contrast, as identifying themselves as masculine, boys separate themselves from their mother and fetter their sense of empathic tie. Since femininity then is defined through attachment, women view and understand their world through connectedness, cooperation, and communality. This is fundamentally different from men's ways of understanding the world, which emphasizes and values separation, competition, and individuality (Belenky et al., 1986).

Identities are cognitive schemas: internally stored information that serve as frameworks for defining situations and interpreting experiences (Stryker & Burke, 2000). For example, in researching how children interpret Kohlberg's classic problem on moral development (should Heinz steal a drug that he cannot afford, in order to save his wife's life?), Gilligan (1982) found that boys see the dilemma as a math problem, solved by logic and infallible laws. Girls, on the other hand, see the dilemma as a narrative of relationships that extend over time.

We make choices that maintain our cognitive schemas and reflect self-identity not only when interpreting situations, but also by finding or creating situations in which they can be expressed and validated by external sources. Carlone and Johnson (2007) and Zeldin and Pajares (2000) found that recognition by others was a key component of science and math identity development for women.

Through surveys and interviews, SL students have reported increased awareness of their potential to make an impact, increased self-efficacy, a new passion for their vocation, and enhanced problem-solving and communication skills. Students' involved in SL activities have also demonstrated an increased application of knowledge as well as a more complex quality of analysis when presented with community problems (Astin, Vogelgesang, Ikeda, & Yee, 2000; Barrington & Duffy, 2007; Lord, 1999). These positive effects of service learning are due to students' discussions and interactions with each other and with faculty. The extensive reflection and dialogue is the critical component of successful SL programs (Astin et al., Eyler & Giles, 1999; Jacoby, 1996). So, the structure of SL promotes interactions, connections, and an awareness of responsibility for one another. It also encourages validation and recognition by others. These are core components of women's gender identity, and helps explain why women are drawn to SL programs. Women identify with the roles and behaviors provided by SL activities, because they are the same roles and behaviours they identify with as women.

Methodology

Verbal Protocol Analysis (VPA) has been used extensively in studying the design processes of engineers (Atman et al., 2005; Ennis & Gyeszly, 1991; Christiaans & Dorst, 1992; Mullins, Atman, & Shuman, 1999; Radcliffe & Lee, 1989). However, past research typically analysed drawings or written reports based on some theoretical task. The purpose of the current research was to investigate the design process using VPA collected during an alternative mode: that of prototype construction.

Two SL and 2 non-SL engineering seniors were asked to participate in a design experiment. (Their disciplines can be found in Table 1.) The students were drawn from a Student Teacher Outreach Mentorship Program (STOMP) at a private New England university. It was a sample of convenience, as the students were known by the STOMP program manager. Students were tested in a small conference room within the engineering department. A small video camera was mounted on the ceiling that focused on the participants' hands. (Faces could not be seen.) They were told the purpose of the study and given a practice think-aloud project of putting together a 24-piece puzzle. When the subjects finished the puzzle, they were given an information sheet that explained the design task, which was to develop a jar opener for individuals that had the use of only one hand. Laid out on a large table were 15 sets of cards (each set made up of between 5 and 12 additional cards) that offered various snippets of information. The information sheet explained that they could choose whichever information cards they thought might help them formulate a solution. Some information was based on the Massachusetts Standards of the engineering design process. Some information was totally irrelevant. The purpose of the diverse choices was twofold: 1) to see if students could cull the important information necessary to solve the design task and 2) to help formulate design profiles as identified by Kruger & Cross (2006). The cards were titled: Talk to Jim (an amputee), Speak with Mary (a stroke victim), Learn about Amputees, Learn about Stroke Victims, Review First Principles of Physics, Talk to Jar Manufacturers, Examine Elementary Mechanics, Read Technical Descriptions of Prototype Jar Openers, Build a Prototype, Look at Jar Variables, Look at Other Models, View Available Materials, Investigate Aesthetic Options, View Unnecessary Nonsense, and Plan/Draw/Sketch.

LEGO® pieces were the medium used for building the prototype. When subjects chose the *Build* card, they were handed a kit of LEGO parts and were advised to use the pieces simply to get their idea across, and to not be concerned with the limitations of the LEGO pieces. While the functionality of the pieces did not allow heavy force to be used to open a jar, the fact that they could be assembled, taken apart, and reassembled quickly and easily outweighed this disadvantage. In addition, most students are at least somewhat familiar with LEGO pieces.

Data Analysis

Content analysis was employed (Creswell, 1998; Patton, 2002). This involves searching through text for recurring patterns, words, or themes; creating groups of words and phrases; developing a coding or classification system; and determining each category's significance. Once groups of categories were created, constant comparison (Patton) was used to insure internal homogeneity and external heterogeneity of the categories. Internal homogeneity concerns the extent to which each entry within a category was similar to every other entry in that category in a meaningful way. Was there cohesiveness within each category? This also enhanced external heterogeneity, which concerns the extent to which differences between categories are distinct and clear. Was each category independent?

Since the analyst is the research instrument, there is an element of subjectivity when interpreting other people's thoughts. However, two researchers checked category entries for internal homogeneity and external heterogeneity. Some items were questioned. After a brief discussion, some items were deleted from the category, some remained, or new categories were generated until a consensus was reached.

Results

All subjects were skilled at analysing other models as well as their own work, all were able to design and build a prototype jar opener, and all completed the task in about ninety minutes. However, even with this small sample, patterns emerged and we saw differences in the engineering design process between SL and non-SL students, as well as differences between the sexes.

The SL students identified and framed the problem more quickly than the non-SL students. At 12 minutes, the SL male said, "It looks like the things we need are some sort of base to stabilize the jar, and then some way to lock it in, and then a third component to turn the lid." The SL female similarly framed the problem at 12 minutes. However, the non-SL male, at 9 minutes said, "You have to find a way to seal (the lid) down with perhaps an o-ring . . . to provide a seal . . .'cause jars are pretty much used for your liquid containment." At 21 minutes, he said, "It requires redesigning jars in general . . . Talk to the manufacturers of jars, see if you could get them to change their designs." Finally, at 23 minutes, after wondering about the client's countertops, declared, "What you need is something that can be stationary and grip the jar, while they twist the jar." The non-SL female never did clearly state the problem. At 50 minutes, she placed a sample jar on a LEGO baseplate and said, "Somehow, you just like, keep it there." Our sample of SL students framed the problem more quickly than the non-SL students. This finding is similar to that of Eyler & Giles (1999) who reported that students who had experienced community service had an easier time identifying the problem to be addressed.

Another major design difference that emerged was that the SL students understood more clearly the limitations of the clients (perhaps because they read the *Jim* and *Mary* cards first) and that they were designing a jar opener to be used with one hand. The non-SL students appeared confused about the clients' abilities. The non-SL female was told explicitly by one of the researchers that Jim did not have a second arm (the cards also explained that Jim does NOT have a prosthetic limb), yet referred to his second arm on two later occasions. The non-SL male similarly referred to Jim's prosthesis to stabilize the jar, and commented that an amputee might have trouble coordinating his 2 hands. He said, "The major difficulties they would probably have doing is the uh, coordinating the two hands or using two hands if you're an amputee." (Upper limb amputees don't have 2 hands.) And at 54 minutes he said, "I'm making it specifically for them. They were lefties now, right?"

A third unexpected outcome was that the SL students appeared more skilled at discriminating between useful and insignificant information, and assessed rather quickly cards with information of no value. At 7 minutes, the SL female said, "She didn't think she was having a stroke . . . not all that relevant to what I need to design." After reading *Basic Mechanics* cards, the SL male commented, "Talking about stresses, deformation. I don't think that'll be a huge issue." The non-SL students however, tried to apply the information to the task, even when the information was superfluous. After reading an insignificant bit about stress, the non-SL female commented, "It's talking about bending stress . . . so I guess, if you're like, squeezing this jar, and it's like a plastic jar . . . if you clamp the bottom it might not stay that shape." Later she commented, "Don't use a steel chain. I'll figure out what that means."

The SL subjects also made more references to their meta-cognitive skills. That is, they were conscious of what they knew and what they didn't know, and they took stock periodically of their knowledge-building progress.

Differences between genders also emerged. The women were more client focused, averaging 17 comments regarding the client (e.g., "I'm keeping in mind that people that this is for probably are only gonna be able to use one hand.") while the men referred to the client an average of 8 times. The men however, made more comments about the limitations of the Lego pieces (e.g., I'm gonna make it stationary, like attached to the base plate as best I can with what we've got here."), averaging 15.5 comments compared to 2.5 comments for the women. This might be due to different sources of self-efficacy. Bandura (1977) claimed that self-efficacy is strengthened by mastery experiences as well as verbal persuasion. Zeldin, Britner, & Pajares (2008) extended this theory and found that men and women had different development paths for self-efficacy. While men relied more on mastery experiences, women (particularly in male dominated fields) depended more on verbal persuasion: critical support from family, friends, and supervisors. Self-efficacy also is domain dependent. It could be that the men in this sample were more conscious of their skills in model building and hence, more aware of the limitations of the LEGO pieces. For the women, model building skill was not so crucial.

The following is a chart of some of the categories that emerged from the data.

Table 1. Number of Phrases for Each Category

	Refers to Client	LEGO Limitation	Evaluations	Meta-cognition	First 3 Card Choices
SL female Environmental Eng. STOMP, EWB	22	3	42	12	Amputee Jim Mary
SL male Mechanical Eng. STOMP	7	15	71	25	Amputee Mary View Jars
Non-SL female Civil Eng. Non-SL	12	2	35	4	Other Models Jim Mary
Non-SL male General Eng. Non-SL	9	16	43	6	View Jars Available Materials

Example of Client phrase: *"That might be annoying for whoever is using it."*
Example of LEGO Limitation phrase: *"So ideally this will pivot on a much stronger simple pin here, um, which LEGOS can't reproduce"*
Example of Evaluation (judgment) phrase: *"Yeah, that fixed it up easily enough. Yeah, that works."*
Example of Meta-cognition phrase: *"Alright, so learning a little bit about amputees."*

Conclusion

From this small sample, differences in problem perspectives and design processes emerged between SL and non-SL engineering students during this hands-on design task. The SL students identified and framed the problem more easily and quickly, had a more accurate understanding of the client's limitations and needs, and were more skilled at discriminating between important and insignificant information.

Differences between the men and women also emerged, with the women referring to the client more than the men during their design and construction. That the women were more client-focused is not surprising since women identify with connections, relationships, and communality.

It is important to keep in mind that SL students self-select and as such, bring to the table a different set of skills and personalities than students who are not involved in such activities. They choose SL programs via the nature of who they are. Any differences we see in the design process cannot be totally attributed to SL programs. The question becomes, what discriminates these two groups of people? From this research we know that women identify with activities that emphasize social relevance, and human relationships. But more needs to be done for a better understanding of what types of students are drawn to SL programs, and which types are not.

Recommendations/ Future Research

Service learning programs incorporate community need and their source efficacy, why they work in enhancing complex problem solving and increasing the application of knowledge, is through extensive reflection and dialogue with each other and with faculty. We need and seek out opportunities in which our identities can be expressed and reinforced. For women, it is making connections with others: precisely what SL activities provide. If universities are serious about attracting more women to STEM disciplines, it might behoove them to incorporate and strengthen existing SL activities into their engineering programs.

This was a small sample size with a select group of students from one SL program at a private college. Future plans are to expand our sample population to include all levels of students from other SL programs (e.g., EPICS and EWB) at other universities.

References

Astin, A. W., Vogelgesang, L. J., Ikeda, E. K., & Yee, J. A. (2000). *How service learning affects students.* Los Angeles: Higher Education Research Institute, University of California.

Atman, C., Cardella, M., Turns, J., & Adams, R. (2005) Comparing freshman and senior engineering design processes: an in-depth follow up study. *Design Studies*, 26, 325-357.

Bandura, A. (1977). Self Efficacy: Toward a unifying theory of behavior change. *Psychological Review*, 84, 191-215.

Barrington, L. & Duffy, J. (2007). *Attracting underrepresented groups to engineering with service-learning*. Paper presented at the annual conference of the American Society of Engineering Education, Honolulu.

Belenky, M.F., Clinchy, B.M., Goldberger, N. R., & Tarule, J.M. (1986). *Women's Way of Knowing: The Development of Self, Voice, and Mind.* New York, NY: Basic Books.

Carlone, H. & Johnson, A. (2007) Understanding the sciences experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching, 44*. 1187-1218.

Chodorow, N. (1974), Family structure and feminine personality. In M.Rosaldo & L. Lamphere (eds.) *Women, Culture, and Society* (pp. 43-46). Stanford, CA: Stanford University Press.

Christiaans, H., & Dorst, K. (1992). Cognitive models in industrial design engineering: a protocol study. *Design Theory and Methodology,* 42, 131-137.

Coyle, E., Jamieson, L., & Oakes, W. (2004). EPICS: Engineering Projects in Community Service. *International Journal of Engineering Education,* 21, 139-150.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.

Ennis, C. & Gyeszly, S. (1991). Protocol Analysis of the Engineering Systems Design Process. *Research in Engineering Design,* 15-22.

Eyler, J. & Giles, D. (1999). Where's the Learning in Service-Learning? San Francisco: Jossey-Bass Publishers.

Gilligan, C. (1982). *In a Different Voice*. Cambridge, MA: Harvard University Press

Jacoby, B. (1996). Service learning in today's higher education in B. Jacoby (Ed.) Service Learning in Higher Education (pp. 3-26). San Francisco: Jossey Bass Publishers.

Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: Strategies and outcomes. *Design Studies,* 27, 527-548.

Lord, S. (1999, November) *Service-Learning in Introduction to Engineering at the University of San Diego: First Lessons.* Paper presented at the 29th annual ASEE/IEEEE Frontiers in Education Conference, San Juan Puerto Rico.

Matusovich, H., Follman, D., & Oakes, W. (2006). *Work in Progress: a student perspective. Why women choose service learning.* Paper presented at the 36th ASEE/IEEE Frontiers in Education Conference. San Diego, CA. October 28-31.

Mullins, C., Atman, C., & Shuman, L. (1999) Freshman Engineers' performance when solving design problems. *IEEE Transitions on Education*, 42, 281-287.

Patton, M. (2002). *Qualitative Research and Evaluation Methods*. Thousand Oaks, CA: Sage Publications.

Radcliffe, D. & Lee, T. (1989). Design methods used by undergraduate engineering students. *Design Studies*, 10, 199-207.

Stryker, S., & Burke, P. (2000). The past, present and future of an identity theory. *Social Psychology Quarterly,* 63. 284-297.

Zeldin, A., Britner, S., & Pajares, F. (2008). A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *Journal of Research in Science Teaching*, *45*, 1036-1058.

Zeldin, A., & Pajares, F. (2000). Against the odds: Self-efficacy beliefs of women in mathematical, scientific, and technological careers. *American Educational Research Association,* 37. 215-246.

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