Mechanisms for Implementing Service Learning: Analysis of Efforts in a Senior Product Design Class in Mechanical Engineering

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Abstract
Interest in applying and studying service learning in engineering courses is increasing due to both the experiential learning and values-based approach it offers. Integration of service learning into a required senior-level mechanical engineering product design class was undertaken and the cognitive and social effects of the pedagogy were studied through use of a pre-post survey tool. In this paper, we focus on the results of three main questions for study: 1) whether students' perceptions of their ability in various engineering skills changed over the course of the class, 2) whether students' perceptions of career goals changed over time, and 3) whether students' interest in community service changed over the course of the class. Results indicate that students perceived learning gains in key product design areas such as ability to design new products, creativity, and problem solving, and some differential effects were found for women. Students, particularly minorities, also increased their orientation toward a service approach, changing their professional aspirations away from consulting and medicine to more innovative product development work and graduate research while increasing their overall interest in community service and their beliefs about engineers' social responsibility.

Introduction
Service learning is a form of experiential education designed to enhance learning and provide practical outcomes through the integration of academically appropriate community service projects into coursework. In contrast to general experiential learning models, service learning adds the key benefit of directly connecting active learning with a social context. Service learning helps students to understand civic responsibilities and the application of technical skills to local and global contexts that they would not typically experience while at university or in the general job market once they graduate.

Academic and industry leaders have emphasized the need for engineering students to develop core competencies in creative problem solving, group skills, design skills, and global awareness, such that engineers become an integral part of the leadership in setting public policy, industry, and corporate agenda [1, 2]. Educating engineers who not only excel technically but who are also ethical, socially aware, and globally sophisticated is a major challenge for today's engineering schools. Service learning theory and practice provides a model for influencing such positive social and cognitive change by providing students with a learning environment in which to think about the larger context of their education as well as their role as members of society. The conceptual and empirical support that learning theory provides for service learning [3, 4] and the fact that engineering programs using service learning indicate quite positive results [5, 6, 7] are compelling reasons to further integrate and study this pedagogy.

Like other engineering schools, MIT strives to balance advanced specialized learning and research with general professional and human development. As ABET guidelines suggest [8], professionals in engineering and other technical disciplines should not only be domain experts but also skilled communicators proficient at understanding and dealing with global issues, ethical challenges, and complex problem-solving. MIT's service learning program was created to help educate students in real-world contexts that enable them to experience and master these areas within and beyond a subject domain. In this work, we will describe the efforts of MIT's service learning program with respect to one particular class: Product Engineering Processes, better known at MIT as 2.009.

2.009: Product Engineering Processes

2.009 is a one semester course, offered once a year in the fall term and is the required senior-level product design class in the mechanical engineering department (ME) at MIT. The class is project based, and as such, the focus is on applied engineering work, where students develop analytical, technical, and people skills, and practice applying them to real world situations. Students are required to work in large teams on a complex design problem, in which they go from generating ideas for new products, to concept development, to detailing and building a working prototype. Team projects therefore are the key component through which students acquire and apply technical and managerial skills to design, build, install, test, and improve a complex product. 2.009 provides students the opportunity to develop a broad understanding of the product development process and the steps and methods required for each part of the process. Teams of 16-18 students, work with a budget of approximately $6,500 per team, to design a new product and finally to build a working alpha prototype. 2.009 is based on extensive lab participation and out-of-class preparation in groups and as individuals, and is perceived to be one of the most demanding classes in the ME curriculum from the perspective of both the instructors and the students. Given the complexity and scope of the assignment, students are provided intense mentoring and guidance through lectures, labs, individual meetings with faculty mentors, and a detailed website, <http://web.mit.edu/2.009>, that is updated almost daily during the semester.

The class is structured to guide students to focus systematically on an appropriate design concept over the course of the semester.

- All students are first randomly split into teams within recitation schedule constraints, but selection into teams is controlled using certain criteria: i.e., all teams have approximately the same make-up by gender and ethnicity. In addition, pre-existing affiliate groups (such as living groups) that can significantly change team dynamics are not allowed to self-select into the same team.

- Each of the teams is randomly split into sub-teams, allowing students to develop partnerships with a smaller band of teammates and creating conditions for within-team competition. Sub-teams each come-up with, develop, and refine different product ideas over the course of the semester. After honing a range of product ideas down to one refined design, sub-teams merge and work together to create the final alpha prototype.

▪ Aside from the course instructor, each team is also assigned two faculty mentors and one or two alumni consultants that help steer project ideas and guide the product development effort.

▪ Over the course of the semester, students are asked to develop a broad range of product ideas that are then narrowed towards a specific, well developed, workable product possibility. This process takes place through seven main steps (shown in pictures 1-6):

1. Idea presentation: Each sub-team prepares three different posters illustrating each section's three best ideas for a product. Posters include a simple sketch and significant information that relates to the idea (such as potential customers and technical feasibility estimates). The poster presentation assignment is intended to help students learn how to prepare a 'clean' poster and how to describe a product idea in a very short amount of time, roughly the amount of time available to pitch a new idea to an executive.

2. Sketch model: Each sub-team presents two concepts by making a physical model from semi-permanent materials. Each sub-team presents well-prepared sketches and simple CAD models along with sketch models representing two design concept alternatives, and relevant, technical, market, and customer needs data.

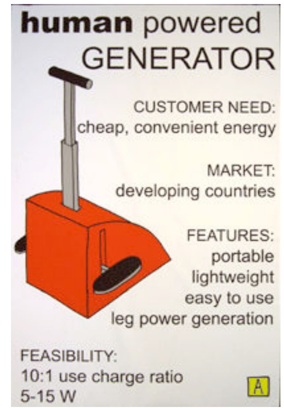
3. Mock-up review: Each sub-team presents a technical or visual mockup and drawing of one concept idea, focusing on illustrating the overall concept, technical feasibility/operational principles of critical systems, and user/product interaction.

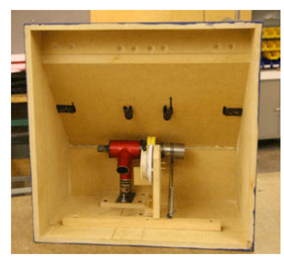
4. The two sub-teams merge into one team and negotiate which product the team as a whole should develop.

5. Assembly Model: Each team designs an electronic assembly model of their product and a product contract document detailing needs, attributes and design specifications.

6. Technical review: Each team demonstrates their functional alpha prototype, points out remaining areas for improvement and gets critical feedback to use in the final presentation.

7. Final presentation: Teams present their alpha prototypes in a public presentation that typically includes entrepreneurs, engineers and consultants from the community. The goal of the presentation is to display the merits of the design: the prototypes, key needs, technical innovation; how it could be realized as a product (business case); and outstanding issues.

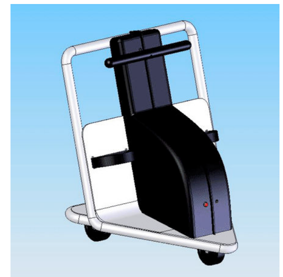




Pictures 1-3, Initial process steps for the Kinkajuice project, a human powered battery charger: (from top) idea poster; sketch model; mock-up review

Service Learning in MIT's Mechanical Engineering Senior Product Design Class

There are a variety of models through which service learning can be integrated into an academic class. While a common model is one where students perform community service by directly volunteering or working within a community agency, that integration method does not often match the curriculum of an engineering class. Hence, in 2.009, students take a project model approach in which they work on solving an applied engineering problem that community clients have targeted as a key need. All teams have the same general task of working with a client to create a working prototype, but teams working on a service learning project provide community service by delivering a product prototype that has a clear service benefit to an identified under-served community group. While all teams communicate and work directly with potential customers, the level of interaction and depth of client contextual understanding varies as a function of client location (international, national, local), time students have to complete intensive course work, and team dedication and interest. However, given the necessity of the product for the community group, service-learning teams frequently have a level of urgency and product meaning built into their client relationship that has often lead to a more intense working relationship and better contextual understanding of client needs and functions.



Pictures 4-6, Final process steps for the Kinkajuice project, assembly model; technical review; final prototype being field tested in Mali by a local client

Service learning projects were first introduced in 2.009 during the fall of 2002. In previous terms, teams worked on specific project themes, such as web-enabled devices or remotely operated products. In the 2002 fall semester, all teams were required to have a community service focus. Students were introduced to project ideas through a "project fair," where community clients gave students ideas for projects. However, there was some confusion during the term about whether local (as opposed to international) projects were appropriate and about the market viability required for projects. Additionally, some of the community clients did not understand that they needed to provide information to the teams about their projects throughout the semester, so communication was limited in some cases, violating a standard tenet of service learning. In fall 2003, the second time service learning was tried in 2.009, all student teams were introduced to the needs of Habitat for Humanity, the community client for the semester. While Habitat for Humanity was the official client, the general theme for the class was "tools for home improvement"; as such many of the projects were not directly tailored to the particular needs of Habitat for Humanity and instead were aimed at general home improvement.

Outcomes from these past classes have resulted in interesting projects that have met real-world needs. For example, service projects have included a battery-powered microfilm projector that uses LED technology to address literacy needs in Mali, a pool table tools for use by children with developmental disabilities, and scaffolding tools for a local Habitat for Humanity organization. The LED microfilm projector project developed in the fall 2002 term went on to win a social entrepreneurship competition, and fifty units were recently produced and shipped to Mali. In a nice connection, a 2.009 team in the fall 2004 term developed a power source for the projector developed in fall 2002.

While the usefulness of the service projects has been validated by many of the community partners, the usefulness of the pedagogy as a learning and teaching tool for students and faculty also needs to be addressed and has been a more neglected area within engineering service learning research. Our data on the learning and social effects of the pedagogy from fall 2002 and 2003 classes have resulted in promising initial findings. Using a post-survey tool, we asked students about their perception of the social and academic effects of the service learning component of the class. Responses indicate that students perceived service learning activities to enhance their understanding of course material, their class motivation, and their knowledge of how to address community needs. Interestingly, these effects were particularly pronounced for women, and there was a suggestive trend regarding a greater effect on minority students. Women, for example, were significantly more likely than men to find service learning helpful to them in learning course material ($t=-2.28$; $p=0.027$) and in influencing their confidence in applying theoretical concepts to real world issues ($t=-2.08$; $p=0.04$).

In the fall 2004 term, more systematic integration and study of service learning in 2.009 was undertaken. First, service learning was integrated into 2.009 through the development of an idea fair, in which students were systematically introduced to a wide variety of potential community partners and service projects that fit the overall design theme of the class: alternative energy. Twelve potential clients presented more than 20 ideas to 2.009 students. Project examples included:

- Photovoltaic systems and energy consumption display
- Design confirmation, fabrication, and testing of a cooler for the cryogenic refrigeration of rubber using chilled air or nitrogen
- Sustainable building technologies for a Haitian school and orphanage
- Low energy refrigeration
- Mechanisms for producing charcoal from agricultural waste materials
- Human-powered generator device

Students were expected to rigorously consider at least one service project during concept development along with their own ideas, and have at least one of their three initial poster ideas come from the idea fair. It was important for class goals, however, to allow students to select community partners and define their own project in a manner that was personally appealing for them. Community partners were aware of their responsibilities to the students and only participated if they could provide a sufficient level of interaction. Of the six fall 2004 teams, four teams selected a service project as their final product.

Projects were identified as service learning if they met two critical criteria. The first criterion is how well a team articulated what the service focus of the product was and demonstrated interest in the service potential of the product. The second criterion is how much a team focused on the importance of the client during concept formation and product development, how clearly they understood client needs, and how much they interacted with their client and took client feedback into account through the development process. The six final team projects are:

Service Learning Projects (shown in Pictures 7-10)
Red Team – Solar Parabolic Power: a solar collector coupled with a steam-powered water pump for the Bethel Business and Community Development Center in Lesotho

Yellow Team – Kinkajuice: a human-powered battery charger for use with the Kinkajou microfilm projector (a previous 2.009 project) being manufactured by Design that Matters <http://www.designthatmatters.org/k2/>

Blue Team – Charcoal Extruder: a method for creating charcoal briquettes from agricultural waste products for Organization for the Rehabilitation of the Environment in Haiti <http://www.oreworld.org/>

Orange Team – Vac-Pac: a small, low-energy refrigeration system for transporting vaccines to rural areas for PATH <http://www.path.org>

Other non-service projects
Purple Team – MP4ever: a magnetic battery charger for powering the MP3 players of runners.

Green Team – Sonic SeeSaw: a pipe organ integrated into a seesaw that plays chords when children use it.

Both the Purple and Green teams interacted with several potential customers but did not have a specific client.

Pictures 7-10: (from top) Solar Parabolic Power; Kinkajuice and Kinkajou projector; Charcoal Extruder; Vac-Pac

Fall 2004 Study Goals

While randomly assigning teams to service learning and non-service learning projects would have allowed us to more directly study the effects of service learning, doing so was not practical given the intensity of the 2.009 class experience and the numerous objectives and requirements of the class. Hence, we primarily incorporated testing tools that could be more easily integrated into the current structure and set-up of the course. A variety of methods were used and data gathered over the semester included pre-post surveys, team diagnostic questionnaires, class exercises, and grades. In this paper, we focus on the results of the pre-post survey tool as it relates to three main questions for study: 1) whether students' perceptions of career goals changed over time, 2) whether students' perceptions of their ability in various engineering skills changed over the course of the class, and 3) whether students' interest in community service changed over the course of the class.

Method

Procedure

At the start and end of the semester, students were asked to complete an online survey that included components about their professional aspirations, their own perceptions of their skills, and their interest in public service and social issues. The pre- and post- surveys were almost identical, with some small differences occurring as a result of technical implementation and a few extra questions in the post survey. The surveys took between 10-15 minutes to complete.

Participants

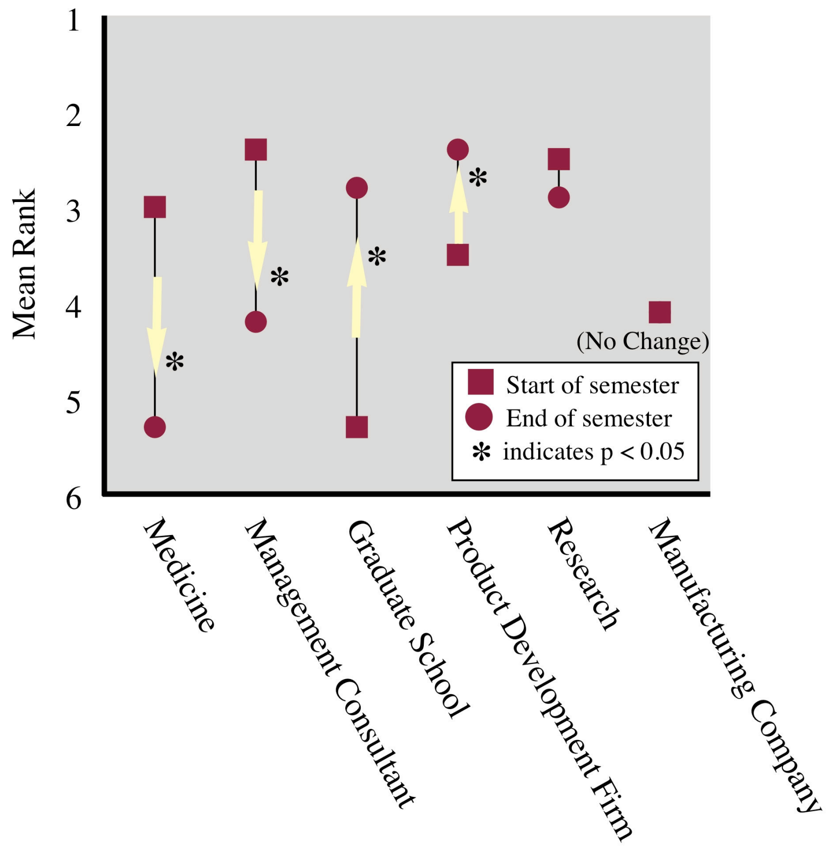
Out of 98 students enrolled in the class, 89 completed either the pre or post survey, and about 50 completed both pre and post survey questions (given the relatively low number of participants, we will use the 0.1 level of significance in this paper). Students were all seniors in mechanical engineering enrolled in 2.009 for the fall 2004 semester. Women constitute 28% of the sample. Eight ethnicities were represented which fell into the following broad groups: Asian (22%), Black (7%), Hispanic (16%), and Caucasian (54%). For analysis purposes, we categorized students into minority and non-minority groups. Our minority group consisted of Asian, Black, and Hispanic students. While Asian students are not an under-represented minority at MIT, they are a minority group within the larger society and many are new to the educational culture, language, and learning styles prevalent in the United States. Our sense is that Asian students would be more similar to other minority groups in how they would use the added support and contextual information service learning can bring to the classroom.

Results

With the regular caveats about the lack of random assignment and control groups, the data reported here should be viewed as an initial indication for the possible roles of service learning within classes such as 2.009. In addition, because all groups were required to consider at least one service learning related project, it is hard to control for the general effects of exposure to service learning pedagogy, since all students were exposed to the method although to different levels.

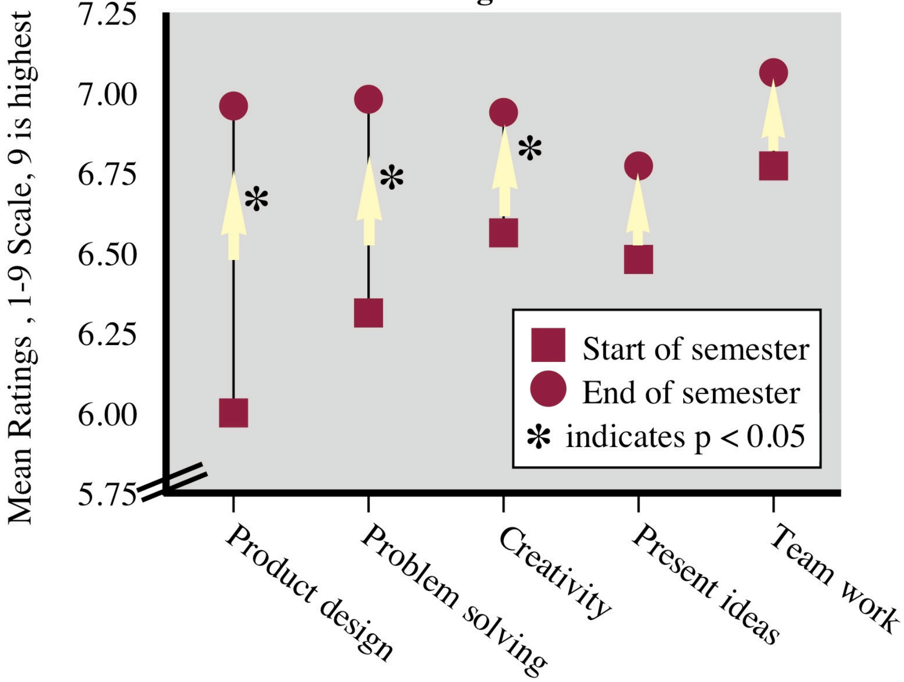
The first component of the survey examined all students' desire to work in a set of possible professions. Students were asked to rank six professions from most to least desirable after graduation, where 1 was the most desirable career choice. Analysis revealed that over the course of the semester, across all six teams, the appeal of two professions increased substantially and the appeal of two professions decreased substantially (see figure 1). Management consulting [$F(1,51) = 54.12$, $p < 0.01$] and medicine [$F(1,51) = 130.61$ $p < 0.01$] decreased in appeal and working in product development firms [$F(1,51) = 28.56$ $p < 0.01$] and attending graduate school [$F(1,52) = 77.58$, $p < 0.01$] increased in appeal. In general, the trend for the class was to move away from the initially popular consulting and health positions to more engineering / innovative work.

Figure 1: Mean Rankings of Six Professions Before and After the Class



The second component of the survey examined all students' perceptions of their ability on different cognitive skills that related to the engineering objectives of the class. Using a nine-point scale, students rated their ability to design a product, problem solve, think creatively, present ideas and work well in a team. Over the course of the semester, students perceived learning gains in three key product design areas (see figure 2). Student ratings indicated a significant increase in their skill level on ability to design new products [$F(1,47) = 33.46$, $p < 0.01$], problem solving ability [$F(1,47) = 19.04$, $p < 0.01$], and creativity [$F(1,47) = 5.18$, $p < 0.03$]. Mean ratings of two other measured skills, ability to present ideas and ability to work well in a team, also showed improvement over the course of the semester, but the mean differences did not reach significance: ability to present ideas well [$F(1,47) = 2.23$, p = ns], and ability to work in a team [$F(1,47) = 1.5$, p = ns]. In addition, one of the skill-based effects showed differential effects by gender. Female students rated themselves worse on new product design than male students at the start of the semester [$F(1,58) = 14.1$, $p < 0.01$], but had a significantly higher rate of improvement during the semester than male students [$F(1,42) = 7.61$, $p < 0.01$].

Figure 2: Perceived Gains in Key Product Design Skills



The final component of the survey examined all students' attitudes toward community service and social issues more generally. Controlling for gender, students' ratings indicated that an overall interest in community service increased as the semester progressed [$F(1,40) = 3.61$, $p < 0.07$]. Most of the social responsibility effects were more pronounced for minority students, suggesting that they might benefit disproportionately from such classes: minority students expressed more interest in community service [$F(1,41) = 4.10$, $p < 0.05$], in using engineering skills to solve social problems [$F(1,40) = 5.96$, $p < 0.02$], and in feeling they could have an impact on global issues [$F(1,41) = 5.60$, $p < 0.03$]. In addition, at the start of the semester, minority and non-minority students did not significantly differ on their agreement that engineers should use their skill for social benefit, [$F(1, 54) = 2.27$, p=ns] but by the end of the semester minority students' belief in engineers' social responsibility became differentially more pronounced than non-minority students [$F(1,40) = 3.26$, $p < 0.08$]. Thus, relative to non-minority students, minority students gained more of an appreciation for service work.

As mentioned earlier, there were a few questions that were included on the end-of-class post-survey that were not included on the initial pre-survey. These questions were analyzed by comparing the responses of service and non-service teams. One of the questions asked students how useful they felt having real clients was for understanding difficult aspects of the design process. Students who had a service learning related project had a trend toward answering more positively [$F(1,69) = 1.8$, $p = 0.09$, one-sided], suggesting that service learning projects' embedded requirement to focus on client needs did seem to help their ability to understand the design process. Another question asked students how much 2.009 helped them understand their ability to help communities as engineers. Students who had a service learning related project answered much more positively [$F(1,69) = 5.91$, $p < 0.02$], indicating that these students ended-up with a higher appreciation for the social aspects of the engineering profession.

Discussion

This large-scale integration of service learning into a core senior design class was designed with engineering, social, and educational objectives in mind. The analysis of the three main questions presented here (changes in professional aspirations, perceptions of own skills, and interest in community service) revealed that over the course of the semester, students perceived learning gains and increased their orientation toward a service approach. First, students changed their professional aspirations toward engineering/product development and further education and away from management consulting and medicine. Second, the perception of their own skills increased in key product design areas such as ability to design new products, creativity, and problem solving. Third, 2.009 students' attitude became more service-oriented.

In summary, the goal of integrating service learning into a core senior design class has multiple objectives, including acquisition of engineering-related skills, a better understanding of the role of engineering in the global context, and an appreciation for community service. While many of these objectives are long-term objectives and to study them well requires longitudinal follow-up and experimental designs, the surveys conducted here were formulated to capture some of these elements within the scope of the semester. More controlled and longer-term future studies will be able to further expand an understanding of these issues.

General Conclusions

This paper has detailed one approach to integrating service learning into a core senior design course. One of the goals of 2.009 is to help students tie together the engineering material they have learned through their student career and connect it to actual problems encountered in real life work that require creative and innovative solutions. By having all graduating seniors in mechanical engineering exposed to the concept of service learning and to project ideas that can have local and global service impact, we hope to provide a means to broaden students' perceptions of the role engineers can play and empower them to take an active part in contributing to the welfare of world around them.

2.009 students have a history of creating product ideas that are innovative in scope, some of which eventually make their way to the market place. While a subset of past products have had a service focus, fully integrating service learning in the fall 2004 semester resulted in a majority of teams creating products that can have clear societal benefit. The likelihood of students following through entrepreneurially with their product idea increases when the meaningfulness and use of the product need is made explicit [9]. Service learning project ideas are generally inherently connected to strong client ties and explicit social meaning and use, and are thus one way to continue providing students after graduation with the client link, support, and motivation to keep developing their work. The evidence obtained from studying students' perceptions of the class encourages us that students perceive learning gains and are not only open to community service but are interested in taking a socially responsible approach to product design.

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Bibliographical Information

1. Splitt, F.G 2003. The challenge to change: On realizing the new paradigm for engineering education. Journal of engineering education, April 2003, Pp 181-187

2. Fisher, G. M. C. (2001). Renaissance engineers of the future. *The Bridge, 31 (4),* 32-34.

3. Kolb, D. (1984). *Experiential learning: Experience as the source of learning and development*. Upper Saddle River, NJ: Prentice Hall.

4. Bransford, J. D., Brown, A. L. & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience and school.* Washington, DC: National Academy Press.

5. Oakes, W. C. (2004). *Service-learning in engineering: A resource guidebook.* (Available from the Campus Compact, http://www.compact.org/publication/SL_Engineering.html)

6. Hobson, R. S. (2000). The changing face of classroom instructional methods: Service learning and design in a robotics course. *Proceedings of the 2000 ASEE/IEEE Frontiers in Education Conference, Building on a Century of Progress in Engineering Education,* Session F3C. Retrieved February 26, 2004, from University of Pittsburgh, Frontiers in Engineering web site: http://fie.engrng.pitt.edu/fie2000/papers/1512.pdf

7. Tsang, E. (2000). *Projects that matter: Concepts and models for service learning in engineering.* Washington, DC: American Association for Higher Education.

8. Accreditation Board for Engineering and Technology. (2003). *Criteria for accrediting engineering programs – Effective for evaluations during the 2003-2004 accreditation cycle*. Baltimore, MD: Accreditation Board for Engineering and Technology. Retrieved March 1, 2004, from ABET website: http://www.abet.org

9. Ariely, D., Kamenica, E., & Prelec, D. (2004). Man's Search for Meaning: The Case of Legos. (Working Paper). Boston: Massachusetts Institute of Technology .

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