



Engineering Design, Project Management, and Community Service Connected Through Servant Leadership

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Abstract

Servant-Leadership is a leadership paradigm that emphasizes power sharing in decision making processes. It also encourages leaders to serve those they manage by propelling them toward high achievement while promoting their professional growth and self-efficacy. Servant-Leadership is also being pioneered as a teaching pedagogy at the Milwaukee School of Engineering, an approach that is unique because most academic institutions subscribe instead to the service-learning model. In conventional academic settings, instructors are the authority figures with control over content, knowledge, assessment, and course outcomes. By contrast, servant-leadership places instructors at the bottom of an inverted power pyramid where they provide a supportive foundation for the students above them.

The authors hypothesize that this supportive structure lends itself ideally to faculty mentorship of engineering design-and-build projects; for example capstone senior design projects. In well-managed student projects, faculty members do none of the actual design or construction work. Instead, they mentor a team of students toward successful completion of the challenge.

To evaluate the impact of a servant-leadership teaching pedagogy in an engineering setting, an interdisciplinary faculty collaboration was implemented that combined three components: 1) a curriculum-integrated design-and-build project; 2) an industrial engineering project management course; and 3) sponsored service to the community. Service is attractive to college-age people who value global citizenship and stewardship; community projects draw civic-minded perspective students and are highly valued in promoting student recruiting.

Within one faculty member's quarter-long senior-level mechanical engineering thermodynamics course, students designed, built, tested, and deployed three miniature aquaponic demonstration units for the Sweet Water Foundation (SWF), a Milwaukee-based non-profit organization. The SWF mission is to teach the public about sustainable urban agriculture. The project's mechanical engineering (ME) students were supported by students taking an industrial engineering (IE) project management course from a different faculty member. IE students served as project managers. Simultaneously, a third faculty member, expert in implementing servant-leadership as a teaching pedagogy, secured project funding from the Brady Foundation while guiding the course instructors in mentoring students as servant-leaders.

We report qualitative results from this interdisciplinary project guided by servant-leadership. Instructors report best practices learned by mentoring their engineering students through successful project completion using a servant-leadership teaching pedagogy. We also present and analyze survey data compiled from student participants in the university-wide servant-leadership community to quantify the positive impacts on our institution's culture enabled through community service and faculty mentoring projects using the servant-leadership pedagogy.

Introduction

The interdisciplinary collaboration reported here combined three components, 1) a mechanical engineering design-and-build project; 2) an industrial engineering project management course; and 3) service to the community. Synthesis of these elements was accomplished through a pedagogy of faculty servant-leadership. Overarching outcomes of this program included 1) introducing formal leadership training into an engineering curriculum that has historically lacked leadership education, 2) creating an opportunity for engineering students to apply their technical skills to benefit the community, and 3) enabling students to practice autonomy and personal responsibility in directing their own learning.

Servant-Leadership is a leadership paradigm established by Robert Greenleaf in the 1970's that emphasizes power sharing in decision making processes. It also encourages leaders to serve those they manage by gently guiding and propelling them toward high achievement and accomplishment while promoting their growth and self-efficacy. Servant-Leadership advocates a hierarchical structure different from the classical top-down management pyramid often seen in industry and academia. In industry, management rests at the top of the structure supported by workers, and in academia, teachers are authority figures with control over content, knowledge, and course outcomes. By contrast, servant-leadership places managers and teachers at the bottom of an inverted pyramid where they provide a supportive foundation for workers or pupils above them.

The supportive structure of servant-leadership is akin to effective management structures used by engineering faculty to mentor design-and-build projects in engineering programs; senior design projects, for example. In well-managed projects, faculty members do little of the actual design and construction work themselves. Instead, they guide and mentor a team of students to synthesize their existing knowledge as well as develop and master new skills to complete an extensive and challenging design-and-build project. The completed artifact represents the pinnacle and capstone of the students' engineering curriculum while propelling them into their professional careers. When consciously adopted by engineering faculty as an underlying project management pedagogy, servant-leadership is an effective and powerful teaching technique. Faculty become servant-leaders by providing guidance to their students in planning, implementing, and testing their designs.

As a teaching pedagogy used in business, servant-leadership has been shown to increase course impact, meaning, and relevance while empowering students, increasing their confidence, and enriching the student-teacher relationship. [1] Servant-Leadership used in marketing has been shown to increase student knowledge and skills as well as instilling increased desire to contribute positively to their environment. [2] Despite its correspondence to techniques used by faculty to successfully manage engineering design projects, servant-leadership appears to be nearly absent from the engineering education literature. This interdisciplinary project, therefore, opens important new lines of discussion for engineering teaching pedagogy and provides an opportunity to disseminate best practices and lessons learned from an actual servant-leadership-driven course project.

Background

In spite of the metropolitan location of the Milwaukee School of Engineering (MSOE), most of our students are comfortable staying confined within the triangle of the dormitory, the cafeteria, and the classroom. Enabling students to step outside of this artificial paradigm is not only each university's challenge—it's their responsibility. The Office of Servant-Leadership at MSOE was created, in part, to address this responsibility by encouraging students to exercise their humanity while developing critical non-technical abilities including 1) active listening, 2) the capability to be empathetic, and 3) internalizing a sense of self-awareness. By looking outward, students learn how their own needs intersect with the needs of others, and through this realization students learn how to grow communities and become active, engaged citizens. By facilitating opportunities for students to experience service and leadership, they are better able to understand how the tenets of servant-leadership impact their current and future lives.

To meet the challenge of enabling students to step outside the confines of the university to exercise their humanity, the Office of Servant-Leadership at MSOE applied for and received a 3-year, \$160,000 grant from the Brady Foundation. This award allows servant-leadership pedagogy to be applied across leadership and management courses including 'Project Management', 'Leading Project Teams', and 'Managing and Implementing Projects'. To complete these courses, students need to learn and demonstrate competence in project management theory. Simultaneously, they can work on projects that benefit the greater Milwaukee community.

Though our collaboration with the Brady Foundation, Brady Corporation provides both financial and intellectual capital for the benefit of students. Projects are funded that benefit the greater-Milwaukee community. Intellectual capital is transferred from Brady Corporation project managers to students through project mentorship, technical project consulting, and guest lecturing in management courses. For Brady Corporation, alliances are created with both academic and non-profit organizations to empower the company to better the community. For MSOE, faculty are empowered through enhanced student instruction with applied projects. Students are empowered by the opportunity to implement management theory in a real-world. Community partners in Milwaukee's inner-city are empowered by access to resources and expertise to address their explicit needs, especially to reverse poverty and injustice. Examples of organizations benefited by MSOE students through Office of Servant Leadership projects supported by the Brady Foundation include the YMCA of Downtown Milwaukee, Our Next Generation, The United Way of Greater Milwaukee, and the Sweet Water Foundation.

Servant-Leadership community projects are proposed to the Office of Servant-Leadership by MSOE students and faculty in the form of grant proposals. Proposals are vetted by the following criteria. They must:

1. Be technical enough and large enough that a group of 4-5 students can plan out a robust design and implementation strategy (scope, timeline, milestones, resources, etc.);
2. Fit within the timeline of an 11-week academic term;
3. Require between \$1,500.00 to \$3,000.00 to implement; and
4. Include a faculty advisor's participation as a subject-matter expert.

One such project, which we report here as representative of the overall program, was carried out in a senior-level thermodynamics course in the mechanical engineering department of MSOE. This class includes a curriculum-mandated capstone design-and-build project as a major course component.

Students designed, built, tested, and deployed three miniature aquaponic demonstration units (Figure 1) for the Sweet Water Foundation (SWF), a Milwaukee-based non-profit organization. The SWF mission is to teach the public about sustainable urban agriculture. Small, self-contained aquaponic systems like those built by students for this project, serve SWF as centerpieces for outreach and education programs with partner K-12 schools. Aquaponic agriculture is a sustainable food production system that combines raising fish (aquaculture) with plant cultivation in water (hydroponics) in a symbiotic environment where the fish nourish the plants while the plants cleanse the water for the fish. Designing these systems provides a multi-faceted energy-thermal-fluids capstone experience because to function correctly, aquaponic systems must precisely balance flows of energy and mass as well as the exchange of energy and mass between the system and its surroundings.

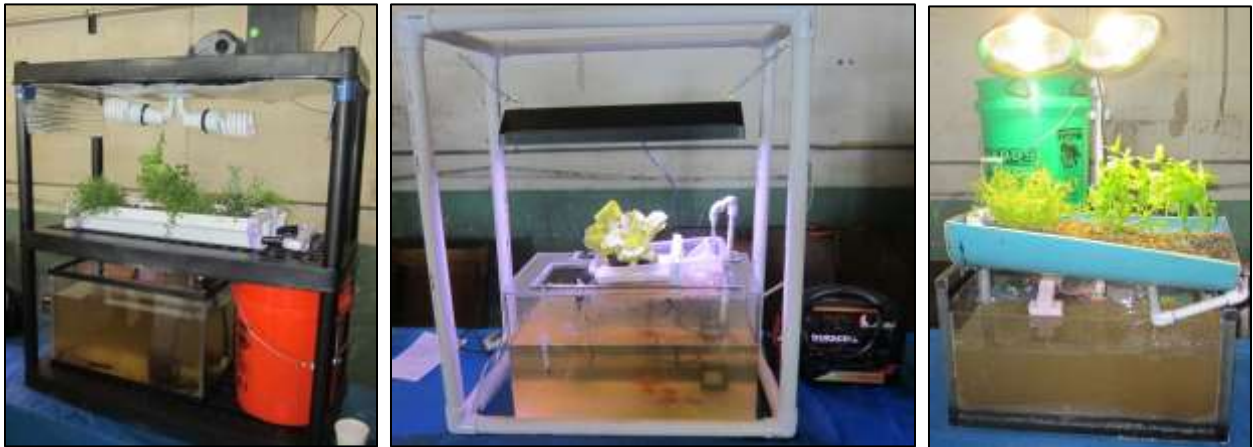


Figure 1: Three aquaponic miniatures were designed and built by students for a senior thermodynamics course. While implementing technical thermodynamic analysis and formal engineering design to create these systems, the students also simultaneously practiced servant-leadership. These systems were donated to SWF to support ongoing K-12 student and teacher education in urban agriculture.

Engineering Servant-Leadership Project Example: Aquaponics Miniatures

Due to the rigorous academic expectations imposed by MSOE, students find it difficult to participate in service and leadership experiences outside of their academic coursework. It is thus appropriate that students receive opportunities to serve and lead within the existing curriculum to ensure these opportunities are a part of their university experience. Curriculum-integrated participation also ensures that students view service and leadership as essential parts of their academic tracks, better preparing them for their chosen careers.

In the summer of 2011, a team of MSOE engineering and business students implemented a 9-month-long capstone senior design project to build a viable, transportable aquaponic food

system. They shipped the finished systems to Faith Orphanage – located in Jacmel, Haiti. The MSOE Office of Servant-Leadership coordinated project fundraising and in-kind donations from the MSOE Rader School of Business and The Home Depot. Through this initiative, a partnership between MSOE and SWF was established to provide the students technical expertise on the design of aquaponic food systems.

In 2012, the MSOE Office of Servant-Leadership leveraged students' newfound interest in aquaponics into one of its Brady Foundation initiatives in cooperation with SWF. A mechanical engineering faculty member received a servant-leadership grant to guide students in his advanced thermodynamics class to design, build, test, and deploy three miniature aquaponic systems. These demonstration-scale systems were delivered to SWF to assist the foundation in its STEM outreach and education for local K-12 students.

At the course outset, the 11 enrolled students self-organized into one team of 3 and two teams of 4 members. They were told they would be carrying out a complete design-and-build project by applying the formal engineering design process they had learned in earlier courses within the mechanical engineering curriculum. Staff from SWF generated a set of qualitative and quantitative customer needs to drive the design process. In the initial project assignment, students were reminded that a formal engineering design-and-build process involves six phases. Each phase of the design process was accompanied by a deliverable assessed by the instructor for a grade. The six phases are as follows.

In the “Planning Stage”, each team performed a literature search to gather information and knowledge about aquaponics systems with respect to 1) physical parameters, 2) principles of operation, and 3) prior art other engineers have designed.

In the “Concept Development” phase, each team delivered an oral presentation in which they 1) quantified aquaponics system design requirements, 2) brainstormed viable concepts, 3) investigated feasibility of each configuration, and 4) down-selected to the most desirable design based on realistic limitations such as fabrication cost.

In the “System-Level Design” phase, each team 1) outlined aquaponics systems performance criteria, 2) decided how these criteria would be measured and evaluated, 3) determined how to implement the design, 4) performed “Orientation Calculations” to estimate and quantify the system’s attributes, and 5) created a bill of materials to facilitate parts ordering.

In the “Detail Design and Fabrication” phase, each team 1) finalized system configuration and materials selection, 2) fabricated parts and assembled a working system, and 3) demonstrated that the system functioned while troubleshooting problems if initial performance failed expectations.

In the “Testing and Refinement” phase, teams 1) ran their aquaponics systems using live plants and animals to demonstrate achievement of customer needs, 2) evaluated how well their aquaponics system performed in meeting stated needs, 3) presented to an audience of K-12 students and teachers about the aquaponics systems and the engineering design process, and 4) reflected on what improvements could be made in future iterations to better address design goals.

Finally, in the “Team Member Assessment” phase, performance of all team members was peer-evaluated using an on-line rubric-style assessment developed from templates created by Reid and Cooney. [3,4]

Students took about one week to complete each step in the design process with three weeks given toward the end of the quarter for the building process. Using the aquaponic miniatures they designed and built for this class project, the students engaged the community by teaching local K-12 students and teachers (Figure 2) about the formal engineering design process underlying aquaponic system creation. Ultimately, the student-built aquaponics systems were then donated to the SWF for use in the Foundation’s on-going STEM education and outreach programs.



Figure 2: Mechanical engineering seniors practiced servant-leadership by teaching Milwaukee K-12 teachers and students about the engineering design process while showcasing miniature aquaponics systems they designed and built as a course project.

Results and Discussion: Aquaponics Miniatures Engineering Servant-Leadership Project

To the authors’ knowledge, this example is the first formal integration of servant-leadership into an engineering course project to be reported in the engineering education literature. From a global perspective, this project’s course integration of servant-leadership into the mechanical engineering curriculum was successful where ‘success’ was qualitatively evaluated by five metrics.

First, all three project teams delivered working aquaponics miniatures that met the stated customer needs within time and budget constraints imposed.

Second, these systems were wholly designed and built by students without direct intervention from the instructor. According to Keith, “the best leaders are almost invisible. That is why, when great deeds are done, the people have a sense of ownership and accomplishment.” [5] In other words, one success hallmark in the ‘great deed’ (building viable aquaponic miniatures) was for the instructor to become an ‘invisible leader’, which he did. In cooperation with the Office of Servant-Leadership, the instructor provided needed teaching, support, guidance, and funding while students completing the project owned the accomplishment as they presented their aquaponics systems to K-12 Milwaukee Public School students and teachers at the semester’s end.

Third, despite some private misgivings (described below) the students politely, positively, and energetically engaged K-12 teachers and students by sharing knowledge of formal engineering design, thereby serving and improving the community through knowledge dissemination.

Fourth, SWF received as donations three new working aquaponics miniatures. These systems will function as centerpieces for SWF’s continuing community service, education, and outreach activities long after the formal conclusion of the thermodynamics course project.

Finally, the students were able to escape from the dormitory-cafeteria-classroom triangle, serve their community, and simultaneously apply advanced thermodynamic analysis to the design of real functioning systems for a real external customer.

Despite these successes, some students were openly hostile to the project, which added an unexpected challenge. One student wrote in an evaluation: “the aquaponics project was completely pointless and a huge waste of everyone’s time... There was absolutely no engineering value in it, whatsoever, especially for a thermo class... Why would someone even consider choosing this as the capstone project for the thermo curriculum?” Another student evaluation contained the following: “the aquaponics project was, quite frankly, a waste of time and involved next to nothing related to thermo.”

Interestingly, similar hostility to community service projects is reported in the service-learning engineering education literature. For example, Tsang et al warn instructors to “be prepared for students who do not wish to participate in design projects that are community-service-oriented.” [6] To provide some context for these hostile comments, all 11 enrolled students had to complete the thermodynamics aquaponics miniature project in parallel with their mechanical-engineering-department-mandated capstone senior design projects. Both are time-consuming design-and-build exercises that carry high stakes for students since both are required for graduation. Thus, negative comments reflect a fundamental observation: for engineering, servant-leadership projects are more time-consuming than conventional course projects due to the need to serve an outside stakeholder on a deadline. A best-practice, therefore, is build more time into courses for servant-leadership projects than is typically given for conventional projects.

To further place negative aquaponics miniature project comments in context, it is helpful to compare this project against design-and-build projects selected by instructors in previous offerings of this thermodynamics course. Examples include 1) calorimeters to identify mystery fluids [alcohols] based on measured density, boiling temperature, specific heat capacity, and

latent heat of vaporization; 2) heat engines converting thermal energy from a candle to mechanical energy by raising a coin from the lab floor to the ceiling; and 3) biomass combustors using a fixed mass of cedar wood chips to boil off as much water from a reservoir as possible.

These energy-heavy projects starkly contrast aquaponics, which draws from a wider variety of disciplines without clear focused emphasis on energy or thermodynamics. Nonetheless, in the instructor's assessment, viable aquaponics miniature design is a thermodynamics-intensive exercise with requires calculations including 1) water evaporation rate determination; 2) pump, grow light, and bubbler energy consumption evaluation; and 3) maintenance of thermal and chemical equilibrium. Student teams complained of not having adequate time to complete the aquaponic miniatures design-and-build project simultaneously with the senior design project. So, the deep thermodynamic analysis required to create excellent aquaponics systems may have been overlooked by students who commented that thermodynamics was not needed for their designs. On the other hand, juxtaposition between aquaponics and energy-focused past projects reveals another servant-leadership best-practice: the selected service project must be extremely relevant to the course in which the project is prescribed. This observation explains why servant-leadership projects work so well in project management classes – students realize the underlying skills taught are widely applicable for a variety of projects, including community service. For engineering servant-leadership projects, if the course/project connection is not plainly apparent to students, it falls on the instructor as 'invisible leader' to make this connection clear to motivate student participation.

Results and Discussion: Overall MSOE Servant-Leadership Program

Servant-Leadership as a university teaching pedagogy espouses concepts such as teamwork, participant focus, growth, and developing the values of its student demographic. As a concept, servant-leadership does not fit prescribed conventional management principles. The multi-dimensional and wide-ranging complexities of the practice of servant-leadership, however, do not preclude quantitative and qualitative analysis of its development, progress, and impact.

The MSOE Office of Servant-Leadership tracks its progress through four instruments:

- 1) Weekly document tracking of various servant-leadership projects;
- 2) Student project evaluations from courses with integrated servant-leadership components;
- 3) Data analysis and reflection performed in yearly assessment reports to the Suzanne and Richard Pieper Family Foundation for Servant-Leadership; and
- 4) Yearly ethnographic studies that track the implementation of servant-leadership.

In 2012, the Office of Servant-Leadership completed a longitudinal ethnographic research initiative as a means of tracking the outcomes measures for servant-leadership at MSOE. Resulting community service and servant-leadership participation data are presented in Figure 3. The full ethnographic data, which includes field analysis and interview data, is included in the 2012 annual report to the Pieper Family Foundation. [7] Data were gathered through three mediums: surveys, interviews, and field analyses. The survey portion of the study was sent to the entire MSOE student body via e-mail, and it asked each student to answer ten questions. So, while the students who participated in the aquaponics design-and-build project were represented

in the population surveyed, the reported results embody the composite response from the entire MSOE student population.

Three areas targeted by the questions are relevant to campus engagement:

- 1) The percentage of students engaged in community service;
- 2) The percentage of students engaged in leadership initiatives coordinated through the Office of Servant-Leadership; and
- 3) The percentage of alumni engaged in community service.

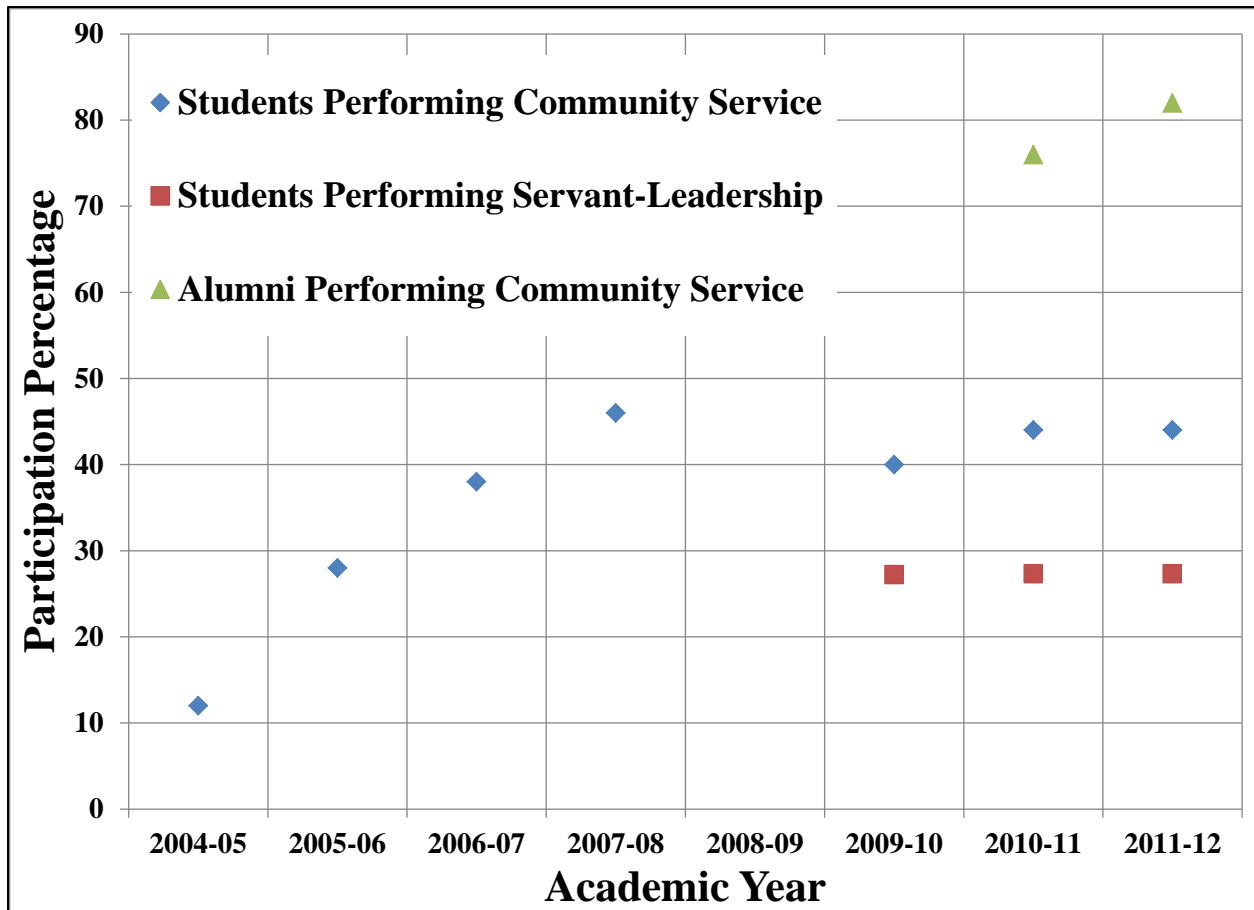


Figure 3: The MSOE Office of Servant-Leadership collects data on community service and servant-leadership participation of students and alumni to evaluate the campus culture impact of the office. Alumni data have been accumulated since 2010, and servant-leadership participation data have been collected since 2009. Note that no data are available for the 2008-09 academic year.

Three quantitative conclusions are drawn from the collected data. First, the majority of the alumni who participated in the study engage in community volunteerism. Second, while only a minority of MSOS students engaged in community volunteerism over the past eight years, participation is generally increasing toward 50% engagement. Third, the quantity of students who participate in servant-leadership initiatives has stayed the same for the past three years. Finally, a qualitative conclusion: based on correlation of survey data with interviews and field observations, the quality of servant-leadership initiatives has improved over the data collection

period. Thus, while the portion of students participating in servant-leadership has remained fixed, the magnitude of their impact has increased over the past three years.

The three primary reasons respondents listed for not participating in servant-leadership opportunities were 1) time conflicts, 2) lack of awareness of sponsored activities, and 3) a misunderstanding of the concepts of servant-leadership.

To increase participation in servant-leadership activities, the following recommendations are suggested. To avoid time conflicts with regular academic commitments, opportunities and activities should be made available during nontraditional school hours and/or on nontraditional days. For example, servant-leadership activities can be scheduled during school breaks to engage students who do not return home for the holidays. In addition large projects should be parsed into smaller pieces that can be accomplished by multiple people working over short periods of time. Servant-leadership endeavors of fixed duration (i.e., one hour, one day, one weekend, etc.) would engage students who cannot make larger commitments of time.

Numerous students surveyed were not familiar with the tenants of servant-leadership and they were not aware of sponsored opportunities through the Office of Servant Leadership. Since one of the most effective means of learning about servant-leadership is through class involvement, diffusion of servant-leadership would benefit from being woven into more courses. As described above, the natural place to offer servant-leadership opportunities in engineering curricula is within design-and-build projects, which are already a required part of all ABET accredited engineering programs. Moreover, the survey data illustrate that few freshmen are involved in servant-leadership. To engage freshmen, servant-leadership opportunities should be offered in project-based introductory engineering courses that form the integral first year experience within many engineering curricula. Since freshman remain on campus for at least three years, they can become ambassadors for servant-leadership to other class ranks and to the next wave of incoming freshmen.

Conclusions

To evaluate the impact of a servant-leadership teaching pedagogy in an engineering setting, an interdisciplinary faculty collaboration was implemented that combined three components: 1) a curriculum-integrated design-and-build project; 2) an industrial engineering project management course; and 3) sponsored service to the community. To the authors' knowledge this project is the first example of servant-leadership pedagogy being reported in the engineering education literature. This silence is ironic because there exists strong correspondence between servant-leadership as a teaching pedagogy and the techniques used by faculty to successfully manage engineering design projects. In other words, engineering faculty who mentor student engineering projects are practicing servant-leadership without even knowing it! We hope, therefore, that this paper opens important new lines of discussion in engineering teaching pedagogy with respect to adopting best practices and lessons learned from servant-leadership-driven course projects.

By analyzing outcomes from a course-integrated community service engineering project where a servant-leadership management approach was intentionally adopted by the instructor, five metrics were observed indicating success.

1. All student teams delivered working systems that met customer needs within imposed time and budget constraints.
2. These systems were wholly designed and built by students without any direct intervention by the instructor. By providing needed teaching, support, guidance, and funding to empower the students toward project completion, the instructor became an ‘invisible leader’, one of the hallmarks of servant-leadership.
3. The project’s student participants served and improved their community through positive and energetic engagement with local K-12 teachers and students to teach the engineering design process and its application to aquaponic system design.
4. The project client, SWF, received three new functional aquaponics miniatures that will be used as centerpieces for continuing community service, education, and outreach.
5. By engaging in and leading a community project, students got off-campus to visit K-12 students and teachers and discovered their humanity (at least in part) all while applying advanced thermodynamics analysis to a real system.

Two best practices also emerged that will assist engineering educators who use servant-leadership projects to avoid future potential pitfalls. First, since servant-leadership projects serve outside stakeholders, they consume more time than conventional in-house engineering projects. Therefore, more time must be built into engineering courses that contain servant-leadership projects. Second, the selected servant-leadership project must be extremely relevant to the course in which it is prescribed, and it falls on the instructor to make this connection clear for the students.

Based on survey data collected to evaluate the overall impact of the Office of Servant Leadership on the culture of MSOE, three quantitative conclusions were drawn.

1. The majority of MSOE alumni who participated in the study engage in community volunteerism.
2. An increasing trend in community volunteerism of MSOE students has been observed over the past eight years, which is trending toward 50% engagement.
3. The quantity of students who participate in servant-leadership initiatives has stayed the same for the past three years. However, based on correlation of survey data with ethnographic interviews and field observations, the quality of servant-leadership initiatives has improved over the data collection period. Therefore the overall positive impact of students’ participation in these activities has increased.

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