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Preparing Engineers for Service

Abstract

George Fox University has a strong service mentality. As the result of the university's "Serve Day" at the Oregon School for the Blind, faculty members developed a passion to connect engineering students with service opportunities that require a technical solution. In the spring of 2010, the engineering department initiated a course sequence required for all engineering students. The program affiliated with the EPICS program (started at Purdue University) and utilized much of their course material for documenting the design process.

Students' initial excitement for the course waned as they began to feel burdened by the large documentation requirements; the instructors agreed with their assessment. In this service-learning context, the intention was to emphasize service, however academic demands dominated. Because of the hands-on design-and-build curriculum, the instructors felt that students could perform effectively as engineers without additional "academic" material overhead. Thus, much of the documentation requirements were curtailed.

When the requirements eased, student passion returned; yet, the instructors soon discovered that with this excitement came reduced project performance. Though the faculty was teaching the design process and engaged students with multiple projects throughout the curriculum, students had not effectively learned how to develop project requirements and specifications. Therefore, the instructors revamped the approach and implemented a detailed design-cycle template with a weekly assessment form using Google Apps. The students were not enthusiastic about the added documentation requirements, but they recognized that these processes enabled them to achieve their goal of providing service to others.

In this paper the authors detail the development of a service-learning course, recounting the various changes in the approach. They suggest that this learning is a prerequisite for effective engineering service and emphasize that if students are to serve, they must first learn.

Introduction

At George Fox University (GFU), the origins of an engineering course with a strong service component are rooted in the missions of both the engineering department ("To prepare technically competent and broadly educated engineers for a life of responsible service emerging from a Christian worldview") and the university ("George Fox University...prepares students spiritually, academically, and professionally to...serve with passion"). From the university's focus on service, an annual event called Serve Day was created in 1999. Each year, the entire campus closes for a day and all students and employees serve throughout the greater Portland, OR, area. In 2006, a group of engineering students and professors went to the Oregon School for the Blind (OSB) to help with landscaping. After working the morning and taking a break for lunch, the group sat down with students and faculty at the OSB and asked if there were any areas of need where engineers could help. The GFU group was surprised by the flood of ideas that came from the students: a device to help students with head posture, a means to help with kick-turns in swimming events, a more robust currency reader, and more. There was an infectious excitement in the room. A famous quote from Frederick Beuchner states, “The place God calls you to is the place where your deep gladness and the world’s deep hunger meet.” For the group, who has a deep gladness in performing engineering, it was a special moment to sit and listen to the deep hunger of blind students who were excited about living and engaging with technology as a means to improve their quality of life. The room was filled with a palpable excitement.

Upon returning to GFU, work began on a postural assist device. This work was done by interested students as an extra-curricular activity. Other similar service projects had been attempted at GFU, some completed, but all were difficult to sustain. The university has a growing engineering program (50 full-time students in the first complete four-year class in 2003, and over 180 in 2011), but there simply was not enough critical mass to maintain the inertia of many of these project ideas. As time went on, the faculty began to look for a way to add service-learning activities directly into the curriculum. The faculty investigated what resources were available to support a course that would focus students on both serving and learning. This effort led to the discovery of the EPICS program started at Purdue University,[1, 2] and faculty members attended the EPICS Conference in 2008 and 2009. After surveying the wide variety of service-learning options, from integration into existing courses to the creation of elective courses, the faculty of GFU felt that the service-learning opportunity was important enough to create a sequence of courses that would be required of all of the engineering students. This course sequence is called Servant Engineering.

Servant Engineering is a 4-semester sequence – 1 unit per semester beginning in the spring of the sophomore year, going through the junior year, and concluding with the fall of the senior year. This schedule provides an overlapping cohort model with first-year and second-year students. The decision to begin the course in the spring rather than at the beginning of the academic year was driven by the timing of the electrical engineers’ Microprocessors course. Since many of the projects require embedded control systems, the expertise is often needed. The actual class time is two hours on a Monday evening in a lab-type format. Students are expected to spend 2.5 hours outside the lab time completing planned tasks.

The ongoing development of the Servant Engineering program at GFU has taken place in roughly three distinct phases:

- Phase 1: the instructors attempted to mimic the basic format provided to us by the Purdue EPICS program.
- Phase 2: much of the EPICS structure was shed to create a much leaner system, focusing primarily on performing the engineering service tasks.
- Phase 3: the EPICS structure was implemented in a manner that was more effective for the Servant Engineering program at GFU, re-emphasizing the importance of learning the engineering design process.

During Phase 3 we began two yearly surveys[4, 5] to help validate the ongoing effectiveness of the course implementation. The first survey allows students to self-assess their engagement with the engineering design process. The second survey assesses students’ perceived influence of service experiences on engineering learning objectives. The results are presented below.

Phase 1 (EPICS documentation)

The Servant Engineering program began in the spring of 2010. At that time there were 39 students, both sophomores and juniors, working on seven projects. The group size for each project ranged from 5-6 students and was purposely multi-disciplinary in their organization. The projects were chosen to fit into the following four tracks: education outreach, community service, appropriate technology for overseas, and assistive technologies. There were two faculty advisers: one responsible for three groups and the other for four groups.

In order to track the progress of a groups' effort, documentation from EPICS was used with limited editing. At the time of implementation, these resources involved a design process document, design document template, project management document, and the individual memo. (Note that EPICS has since updated to a design document template that incorporates both design and project management resources. In addition, the students are expected to review their work via a more extensive individual evaluation rubric rather than the previous individual memo format. The discussion that follows refers to the previous iteration of the EPICS documents, which was implemented in Phase 1 of Servant Engineering.) It should be noted that the EPICS model at Purdue involved a weekly, lecture-style classroom component where much of this content was taught. The Servant Engineering program was implemented in a lab-style environment. Students were expected to learn the design process as part of their service/design experience under the guidance of a faculty member.

Design Document

The design document was 20 pages and references a 25 page design process document. The intent of the design document was to record all the details for each phase in the design process. The design process used by EPICS is shown in Figure 1. While it is clear that there are iterative aspects to the design cycle, the concept of a "gate" is utilized to prevent students from advancing in the design process before their current work has been approved. To explain the function of each design phase, a list of design phases and common tasks is provided (Table 1).

Students were expected to document their design progress through the use of design records. "A design record is a small report outlining the development of some aspect of the design. These are where the meat of the design should be documented. Students will produce design records to document decisions, procedures, research, user analyses, results of testing, and feedback on prototypes as well as the designs for components of the final project."[3] By having this documentation in Microsoft Word format, users were required to find a mechanism to share the document between team members. Unfortunately, any form of sharing required multiple uploads and downloads, which did not allow any real-time collaboration.

Project Management Document

The project management document consisted of three primary sections: the project charter, semester plan, and transition report. The project charter provided a description of the client, stakeholders for the project, project objectives, outcomes and deliverables, and the overall project timeline. The semester plan provides a team organization chart, current status on the

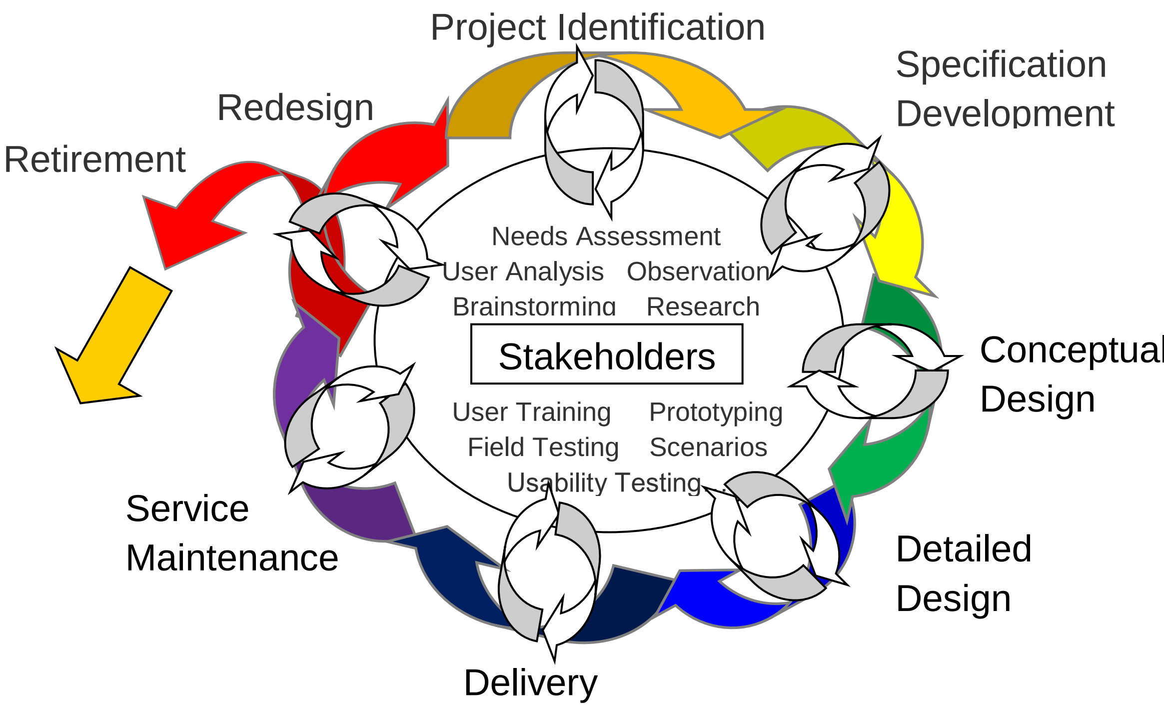

Figure 1 - Visual map of the EPICS design process.

overall project timeline, goals for the semester, semester timeline, and semester budget. The transition report provides a comparison of the actual semester timeline to the proposed semester timeline, a summary of semester progress, and a draft timeline for the next semester.

Individual Memo

The individual memo provided a means for each student to communicate and evaluate their work every four weeks. Students indicate the work they expected to do and how they planned to achieve their tasks. Work that was actually completed is detailed along with reference information pointing to where the project adviser can find the results. The submission frequency of this report was altered to a weekly basis for Servant Engineering.

File Sharing

In order to provide an electronic database of all the project resources, the instructors utilized Active Collab, a software package running on internal engineering servers that was designed for "project management and collaboration." The tool enabled a central repository for team members to place their documents, set up tasks and "tickets," create milestones, create information pages, and other associated project management and collaboration activities. As mentioned above, the Microsoft Word documentation was regularly downloaded/uploaded to this site along with other project files.

Table 1: The EPICS design process with details on each phase.

Project Identification Phase: Goal is to identify a specific, compelling need to be addressed	
Common tasks	• Conduct needs assessment (if need not already defined) • Identify stakeholders (customer, users, person maintaining project, etc.) • Define basic stakeholder requirements (objectives or goals of projects and constraints) • Determine time constraints of the project
Gate 1: Continue if have identified appropriate EPICS project that meets a compelling need	
Specification Development Phase: Goal is to understand "what" is needed by understanding the context, stakeholders, requirements of the project, and why current solutions don't meet need, and to develop measurable criteria in which design concepts can be evaluated.	
Common tasks	• Understand and describe context (current situation and environment) • Create stakeholder profiles • Create mock-ups and simple prototypes: quick, low-cost, multiple cycles incorporating feedback • Develop a task analysis and define how users will interact with project (user scenarios) • Compare to benchmark products (prior art) • Develop customer specifications and evaluation criteria; get project partner approval
Gate 2: Continue if project partner and advisor agree that have identified the "right" need, and if no existing commercial products meet design specifications.	
Conceptual Design Phase: Goal is to expand the design space to include as many solutions as possible. Evaluate different approaches and selecting "best" one to move forward. Exploring "how".	
Common tasks	• Conduct Functional Decomposition • Brainstorm several possible solutions • Create prototypes of multiple concepts, get feedback from users, refine specifications • Evaluate feasibility of potential solutions (proof-of-concept prototypes); select one to move forward
Gate 3: Continue if project partner and advisor agree that solution space has been appropriately explored and the best solution has been chosen.	
Detailed Design Phase: Goal is to design working prototype which meets functional specifications.	
Common tasks	• Design/analysis/evaluation of project, sub-modules and/or components (freeze interfaces) • Complete DFMEA analysis of project • Prototyping of project, sub-modules and/or components • Field test prototype/usability testing
Gate 4: Continue if can demonstrate feasibility of solution (is there a working prototype?). Project Partner and advisor approval required.	
Delivery Phase: Goal is to refine detailed design so as to produce a product that is ready to be delivered! In addition, the goal is to develop user manuals and training materials.	
Common tasks:	Complete user manuals/training material Complete usability and reliability testing Complete delivery review
Gate 5: Continue if Project Partner, Advisor and EPICS Admin agree that project is ready for delivery!	
Service/Maintenance Phase	
Common tasks:	Evaluate performance of fielded project Determine what resources are necessary to support and maintain the project
Gate 6: Project Partner and Advisor approve continued fielding of project. If not, retire or redesign.	
Retirement or Redesign	

Phase 1 Course Evaluation

Operationally, the Active Collab system proved difficult to work with. Authentication management became a challenge, specifically for external participants who did not have the "normal" student accounts. Many of the project management features (milestones, tickets) simply created more work than the value they provided. Document versioning was not well supported, and students had a difficult time maintaining the many versions of the documents that they were generating.

The documentation structure enforced a linear concept of the design cycle that did not necessarily line up with what students were experiencing in the project. Student conversations and evaluations indicated that they wanted to spend time building the service projects and not filling in the various aspects of the design documents. Furthermore, the instructors were also somewhat confused by the seemingly rigid nature of the "gates" - knowing that engineering design is more flexible in its iterative process. Looking back, the instructors made the mistake of assuming that students understood well the engineering design process and could operate well without this linear structure.

Assessment of the course was provided via open-ended written reflections. Students indicated that the documentation requirements were overwhelming the service and design aspects of the course. In spite of their frustration with the documentation, students indicated that they valued the service aspect of the course.

The instructor's assessment mirrored that of the students. The focus of the course was incorrect. In the pursuit of providing resources to help students not waste time, the instructors felt students spent an exorbitant amount of time documenting rather than engaging in the design process.

Phase 2a (Limited documentation)

Before the beginning of the second semester of Servant Engineering (fall 2010), the instructors decided to scale back on the documentation. The individual memo was streamlined to simply reflect the tasks expected and include a link to documentation supporting what had been accomplished. Furthermore, a new "team meeting" was expected for each project group. Initially, the course met for two hours on Monday evening and students were expected to work for three extra hours during the week. The instructors altered the structure of the three extra hours by requiring students to meet as a team for 1.5 hours at some time during the week (and still perform another 1.5 hours on their own). The end result of these two changes (virtually eliminate the documentation requirements other than a scaled-down individual memo, and introduce the team meetings) made students more accountable for their work and also allowed them to spend more time working and less time documenting. As a result, great progress was made on a number of projects. Students were encouraged, faculty advisers were encouraged, yet it was a bit of a mirage.

Phase 2b (Limited effectiveness)

With the start of the third semester of Servant Engineering in the spring of 2011, the course experienced its first transition of personnel---the seniors moving on and a new group of sophomores joining each project. The class now had 52 students (up from the prior 39) participating. To better utilize each team member, instructors decided that project teams would be reduced to three to four students per project, resulting in 8 additional projects. To properly advise the extra projects, two additional instructors were added to the course.

A change in the project support structure also occurred in the spring of 2011. Many of the projects required some sort of embedded controller, yet there were not enough skilled electrical engineering students in the program to distribute to each project. The second-year electrical engineering students (who were taking the Microprocessors course in the spring) were collected into one team and used as “contract employees” for the other projects, supplying expertise when needed and also handling a couple of projects of their own.

The semester began well as there was a lot of initial excitement from both the students and the instructors continuing from the prior semester. However, as the new semester progressed, the instructors began to experience a significant degree of stress. Managing the projects became more and more difficult as students did not seem to have a clear direction on what they were doing. Some of the original projects continued performing well, but others began to flounder, and the newer projects seemed to have a difficult time getting underway. The students still seemed engaged, and were working hard - in fact, they felt that they were making progress. However, as the instructors began to probe deeper into the workings of different projects, it became clear that the students were eager to purchase parts and build solutions for problems that did not necessarily match the original intent.

As the semester came to a conclusion, it was evident that something needed to change. The freedom that the students received from the lighter documentation load resulted in a wild, yet uncontrolled frenzy of activity. The instructors recognized that it was not the freedom of the second semester that produced some great results, but the foundation laid by the drudgery of the first semester’s documentation work that forced students to engage with the details of the engineering design cycle - specifically the problem definitions and specifications. Spending time committing these areas to print, and having the team and project adviser iterate over the details put the teams on a proper course. Looking back, it can be likened to firing a rocket designed to go straight in the air. Spending copious amounts of effort on aligning the rocket’s fins and erecting it appropriately on the launch pad provides a much better launch than just putting it into place and hoping for the best. At the conclusion of the third semester, the projects were off course and something needed to change.

Phase 3 (Google Apps documentation)

To solve the issues of limited documentation and structure that existed at the end of Phase 2, the instructors attempted to craft a system that would both serve the unique needs of the program, yet reengage much of the structure that EPICS had set in place during Phase 1. The instructors were still very concerned about reducing the documentation burden on both students and themselves, while still providing a mechanism whereby a project adviser could rapidly assess the state of a given project.

"Design document"

To provide the overall project management, a Google Site template was developed with a bulleted item format to guide students through each phase of the design process. Both advisers and external participants can easily access the site while it still remains private. The online nature of the site provides a location for convenient links back to a shared Google Collection (folder) with both Google-based documents/spreadsheets (which allow for easy collaboration) and other documentation (drawings, legacy documents, etc.).

Individual memo and Project management

Due to the generation of paperwork for the individual memos as well as the need for group-level evaluation, the instructors sought a convenient and robust online tool to support the course documentation. The implementation of the Google Apps platform, recently adopted by the university, provided several benefits. It eliminated the need for the engineering department to support the documentation system as it had with Active Collab. The documentation experience significantly improved for both students and instructors, as the Google Apps platform required only one sign-in for the various documentation tools and eliminated the need for uploading/downloading Microsoft Word documents.. The ability to discriminately share documents and sites was key feature and was further simplified by making Google Groups for both the students in the course and the instructors. (The Groups feature allowed for ease in maintaining the appropriate sharing while cycling students in and out of the program).

Each group now has a "Reporting Form" (a single Google Spreadsheet) that includes tabs for a Gantt chart of the overall project progress, weekly group-level tasks, and weekly team member tasks. The sheets for group and team member tasks include columns for hours worked, percentage of task progress, reference links to a design notebook and other work, and instructor feedback. In addition, at the top of each team member sheet, a link to that team member's "Assessment Form" is provided. The instructors had recognized, mainly from student comments, that the course structure did not provide students with feedback on their academic progress. The Assessment Form provides students with an instructor's "letter grade" and additional notes of their progress on a weekly basis. The grade is evaluated based on a rubric from EPICS.

Future documents

Internal project sites have worked well as a clearinghouse and working database of information for each project. The instructors are currently developing a website for the course as well as a template for public websites for each project. These will not be as technical in nature as the internal sites and will serve to promote the work of students and the Servant Engineering program.

Table 2: Student self-concept of self-efficacy, motivation, outcome expectancy, and anxiety toward the engineering design process. Pairwise contrasts are made between groups of 0, 1, and 2 years of experience with the Servant Engineering curriculum.

	Class of 2014 (0 years)[a]		***Class of 2013 (1 year)***[b]		***Class of 2012 (2 years)***[c]			
Factor†	***M***	***SD***	***M***	***SD***	***M***	***SD***	***F(2, 90)***	***Pairwise contrast***
Self-Efficacy	6.51	1.98	7.89	1.04	8.22	1.58	9.84	$0 < 1 = 2$
Motivation	8.29	0.99	7.80	1.11	8.13	1.65	1.50	$0 = 1 = 2$
Outcome Exp.	6.63	1.92	7.98	1.13	8.27	1.51	9.64	$0 < 1 = 2$
Anxiety	3.95	2.56	2.51	1.74	3.02	2.37	3.67	$0 > 1$

Note. Total sample sizes for all analyses was 93. [a]n = 44. [b]n = 30. [c]n = 19.
† - Wilks' Lambda = .684, $F(8, 174) = 4.55$, $p < .001$

Surveys

To help validate the ongoing effectiveness of the course implementation, two surveys were given to course participants. The surveys were completed by juniors and seniors in mid-December 2011 and by sophomores in mid-January 2012. The first survey is a student self-report of their engagement with the engineering design process. The second survey assesses students' perceived influence of service experiences on engineering learning objectives. For both surveys, the student respondents ranged in age from 19-37 years; the mean age was 21 years. Student responses were grouped by the following anticipated graduation dates: 2014 (sophomores), 2013 (juniors), and 2012 (seniors). A multivariate analysis of variance (MANOVA) with a Tukey HSD (Honestly Significant Difference) post hoc analysis was used to determine if any significant differences were present between student groups for both surveys.

Engagement with design process

A 36-question, online instrument developed and validated by Carberry, Lee, and Ohland, assesses student self-concept of self-efficacy, motivation, outcome expectancy, and anxiety toward the engineering design process via the following respective questions.[4]

- Rate Your Degree of Confidence
- Rate How Motivated You Would Be to Perform the Following Tasks
- Rate How Successful You Would Be in Performing the Following Tasks
- Rate Your Degree of Anxiety In Performing the Following Tasks

For each question, the nine tasks ("conduct engineering design," and eight steps in the design cycle) were rated on a 10-point Likert scale. In the validation of the instrument, the instrument developers confirmed that the average of the responses to the eight steps in the design process correlated to the response for "conduct engineering design." For the results presented in Table 2, the average of the responses for the eight steps of the design cycle was used. There were 12 female (12.9%) and 71 male (76.3%) respondents.

Table 3: Engineering learning outcomes for each class and statistically significant relationships from a Tukey post hoc analysis. Students evaluated each learning outcome on a 10-point Likert scale, where a 7 indicates 70% of a student's learning derives from coursework and 30% from service experiences.

Learning Outcomes[†]	*T/P*[‡]	*Class of 2014 (0 years)*[a]	*Class of 2013 (1 year)*[b]	*Class of 2012 (2 years)*[c]	*F(2, 88)*	*Pairwise contrast*
Apply math science and engineering knowledge	T	7.62 (2.96)	6.94 (2.46)	6.39 (3.17)	1.30	0 = 1 = 2
Design a system, component, or process to meet desired need	T	7.07 (3.29)	4.61 (2.78)	4.39 (2.73)	8.04	0 > 1 = 2
Design an experiment	T	7.07 (3.29)	5.45 (2.59)	5.61 (2.83)	2.78	0 > 1
Analyze and interpret data	T	7.43 (3.17)	7.29 (2.04)	6.89 (2.42)	0.25	0 = 1 = 2
Apply techniques, skills, and modern engineering tools in practice	T	7.00 (3.34)	5.42 (2.50)	5.06 (2.98)	3.76	0 > 1 = 2
Conduct (or simulate) an experiment	T	7.52 (3.18)	6.00 (2.63)	6.72 (2.68)	2.47	0 > 1
Communicate effectively with others	P	5.86 (3.57)	3.84 (2.93)	4.33 (2.52)	3.92	0 > 1
Operate in the unknown (i.e. open-ended design problems)	P	6.31 (3.71)	3.42 (2.77)	4.50 (2.77)	7.34	0 > 1 = 2[*]
Function within a team	P	6.12 (3.45)	3.10 (2.37)	4.39 (3.18)	8.80	0 > 1 = 2
Engage in critical, reliable, and valid self-assessment (i.e. reflection)	P	7.07 (3.08)	3.16 (2.34)	4.28 (3.21)	17.59	0 > 1 = 2
Persevere to complete an engineering design task	P	7.29 (3.24)	4.71 (2.57)	4.61 (2.73)	9.00	0 > 1 = 2
Maintain a strong work ethic throughout an engineering design project	P	6.95 (3.41)	4.74 (2.41)	4.83 (2.66)	6.11	0 > 1 = 2
Understand the impact of your engineering design/solution in a societal and global context	P	6.76 (3.68)	3.61 (2.55)	4.28 (3.08)	9.44	0 > 1 = 2
Identify potential ethical issues and dilemmas of a project	P	6.74 (3.74)	3.39 (2.86)	4.67 (3.07)	9.27	0 > 1 = 2
Knowing what you want to do after graduation (get a job, go to graduate school, etc…)	P	6.69 (3.00)	5.26 (2.54)	5.56 (2.92)	2.53	0 > 1
Recognize the need for life-long learning	P	6.33 (3.15)	5.35 (2.48)	5.72 (2.63)	1.09	0 = 1 = 2

Note. Total sample sizes for all analyses was 91. [a]n = 42. [b]n = 31. [c]n = 18.
[†] - Wilks' Lambda = .511, $F(32, 146) = 1.82$, $p = .009$
[‡] - T = technical skill; P = professional skill
[*] - significance between 0 and 2 was $p = .05$

The results of the data analyses presented in Table 2 indicate that sophomores had a lower self-efficacy and outcome expectancy than either juniors or seniors. In addition, the increase in anxiety toward the design process for sophomores was statistically significant compared to juniors. Motivation to complete the design process was shown to remain constant throughout the Servant Engineering timeframe.

Service experiences contribution to learning outcomes

To evaluate the impact of the Servant Engineering experience on technical and professional learning outcomes, a validated instrument developed by Carberry and Swan was given.[5] The outcomes evaluated on the instrument include the a-k of ABET, Criterion 3. There were 11 female (12.1%) and 70 male (76.9%) respondents. Students evaluated each learning outcome presented in Table 3 on a 10-point Likert scale, where a 7 indicates 70% of a student's learning derives from coursework and 30% from service experiences.

Results of the analysis are presented in Table 3. Note that 4/6 learning outcomes for technical skills showed a statistically significant shift from the sophomore to the junior year (and, in two cases, the senior year). However, "Design a system, component, or process to meet desired need" was the only outcome where the means for juniors and seniors indicated a shift from learning more from coursework to service experiences. As for the majority of the professional skills, the pairwise contrasts showed a statistically significant shift from the sophomore to the junior year (and, in 7/9 of those cases, also the senior year) in achieving learning outcomes more through service experiences rather than via coursework.

Conclusion

The iterations that the GFU course went through speak to the tension that service and learning can have in the educational arena. The objectives for Servant Engineering are for students to be exposed to the way engineers can serve societies around the world with their skill set and to better understand and apply the design process. As a professional engineer, the design process works as more of a free-flowing dance - back and forth between the different phases. For students, their progress through the design process tends to look more like the awkward dance of a teenager at his first dance. Documentation is clearly a necessary part to provide structure to the design process, guiding students through a path that they travel many times throughout their careers. How the documentation is implemented, however, is crucial. The collaborative nature of the engineering profession, as well as many technical resources that students are already familiar with can lend to the enhancement of learning. The adoption of these tools strengthened the Servant Engineering as it returned to the structure that EPICS had offered in its original documents. The assessment of students' self-concepts (are expected to) show that the course is providing a valuable influence in students' perception of self-efficacy, motivation, outcome expectancy, and anxiety toward the design process. In addition, the experience of the Servant Engineering course has enhanced student understanding of some key learning outcomes.

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