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Multidisciplinary Vertically Integrated Teams Working on Grand Challenges

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Multidisciplinary Vertically Integrated Teams Working on Grand Challenges

Abstract

Calls for changes in the attributes that characterize engineering graduates have become common in reports on engineering education in the last twenty years or so. To help realize these changes, we have developed a new approach for engaging engineering undergraduates in projects associated with grand challenges in engineering as outlined by National Academy of Engineering, World Health, and others. The program was created to develop knowledge and skills for engineering design, lifelong learning, multidisciplinary teamwork, effective communication, applying engineering fundamentals to problem solving, and appreciating influences of engineering on people. Undergraduate student teams collaboratively address multidisciplinary research topics associated with grand challenges in engineering. Students participate in the program through teams of ten or more students representing at least three majors and several levels (first-year to seniors). Each team is mentored by one or more faculty members and a graduate student. Started as a small pilot program within a large engineering college in 2012, more than four hundred students have participated in the last three years, earning course credit for one or more semesters.

Survey data show students see value in the program in several areas that were the intent of the program design. These areas include learning for a lifetime, understanding design, functioning on a multidisciplinary team, and understanding societal, cultural, and economic influences of engineering. More than 90% of survey responders report that they "strongly agree / agree" that in this course they have taken opportunities to expand their knowledge, skills, and abilities beyond just completing required assignments. More than 50% of survey responders rated their growth in understanding what engineering can contribute to the society "a great deal", as a result of their involvement in the program. Based on the growth in student participation, continued interest from students and faculty members, the program has been expanded to include industry sponsored projects which are multidisciplinary and vertically integrated. This paper will describe program conception, implementation, and evaluation. The authors will present data on what students perceive as benefits, impact of the program on recruiting for graduate programs, and transferring this approach to industry-sponsored student team research projects.

Introduction

Engineering graduates will face challenges that are increasingly complex and increasingly multidisciplinary (e.g., requiring knowledge of financial and marketing implications, societal implications, cultural influences, etc.). Attributes, knowledge, and skills to address these challenges cannot be developed through traditional engineering science, physical science, and mathematics courses alone. To support students in their efforts to develop these attributes, knowledge, and skills, we have developed a new approach for engaging engineering undergraduates in projects associated with grand challenges in engineering as outlined by National Academy of Engineering, World Health, and others. The program was created to develop knowledge and skills for engineering design, lifelong learning, multidisciplinary teamwork, effective communication, applying engineering fundamentals to problem solving, and appreciating influences of engineering on people.

Program Description

The goal of the program is to provide undergraduate students opportunities to address significant interdisciplinary challenges that incorporate elements of some of the most important engineering challenges. They should learn and apply engineering concepts, principles, and approaches in multidisciplinary contexts and develop their professional knowledge and skills. The intent was to engage over 100 undergraduate engineering students each year in a serious pursuit of ways in which progress can be made on these challenges.

Each semester, the program begins with engineering faculty members. A solicitation is sent to all engineering faculty members inviting proposals to support teams of students. The incentive is that the College provides support for up to one graduate student who will work with an undergraduate student team, usually ten or more undergraduate students. The graduate student will help the team with their technical knowledge and often greater experience about the subject matter. Combining undergraduate students, and graduate student, and one or more faculty members on the project team is similar to the organization of the Vertically Integrated Program (VIP) [1, 2]. This program emphasizes multidisciplinarity to a larger degree than VIP. Faculty members submit proposals that describe aspects of the project including:

- What is the element of the grand challenge to be addressed and how will it be address?
- How do the educational and disciplinary backgrounds of the proposed team members align with the elements of the grand challenge?
- Who is the faculty member (or members) who will advise the students?
- Who is the graduate student who will support the team?
- How will the team maintain cohesiveness over multiple semesters?
- Approaches for letting students know about the opportunities and how they would encourage students to participate.
- Approaches for managing their student teams along with their graduate students. Undergraduate student teams are anticipated to work multiple semesters. Ideally, we would like to see a team working on their identified element of a grand challenge for four or more semesters.
- Mechanisms through which students can earn academic credit while working on their project. Since students will be working on the project for multiple semesters, faculty members will have to identify a set of courses for sophomores, juniors and seniors interested in the program.
- Descriptions of their research areas

Applications are reviewed at the college level and they are supported to the extent that funding allows. Each faculty member (or interdisciplinary faculty team) who is selected will receive support for a graduate student and prototype material development.

Design Rationale

Given the learning outcomes for the program, key program design decisions were made during early development. The rationales for some of these design decisions are presented in the following paragraphs.

Multidisciplinary Teamwork: To develop knowledge and skills associated with this outcome, undergraduate students should work on a project in teams in which other team members are from different disciplines and have different backgrounds. Students should be coached to develop the skills and knowledge that are required to function effectively in teams. For this program, it was decided that students would participate in teams of ten or more students representing at least three engineering majors and several levels (freshmen to graduate students). Each team is mentored by one or more faculty members and at least one graduate student. Ten (or larger) student teams are often organized into smaller teams, usually five students per team. In addition to a faculty member who oversees the project, there is at least one graduate student who helps the faculty member coordinate the project and provides additional engineering knowledge.

Effective Communication: Effective communication skills require knowledge and skills in a range of scenarios that are much broader than end-of-term project reports and oral presentations. Students should encounter multiple situations in which effective communication is crucial to achieving overall goals. They should be required to present and defend project design decisions at different stages of the project. They should be required to communicate with students with different backgrounds, knowledge, and skill sets. Many of the program design choices described in connection with the multidisciplinary teamwork outcome also contribute to development of effective communication skills and knowledge.

Appreciating Influences of Engineering on People: Students in traditional engineering science courses learn concepts of the different subjects and computational procedures that enable them to compute important metrics of the quality of engineering artifacts. However, these courses are often taught in abstract contexts that encourage students to focus on the engineering concepts by removing the specifics of real-world applications. As a result, engineering students often wonder whether and how engineering influences the lives of people. Therefore, projects chosen for the program are pieces of global challenges that various organizations have identified as crucial to addressing the multiple complex, socio-technical challenges facing our world. Three sets of global challenges are often used to illustrate this aspect of the program design. Many faculty members connect their project proposals to Projects That Matter, Fourteen Global Engineering Challenges identified by the National Academy of Engineering, or Fourteen Global Challenges for Global Health, identified by the Bill and Melinda Gates Foundation.

Student Participation

The program was initiated in Fall 2012. Figures 1, 2, 3 and 4 show the number of students enrolled in each academic year, the number of semesters students participate in the program, the range of engineering majors represented in the program, and also classification of participants (freshmen to seniors).

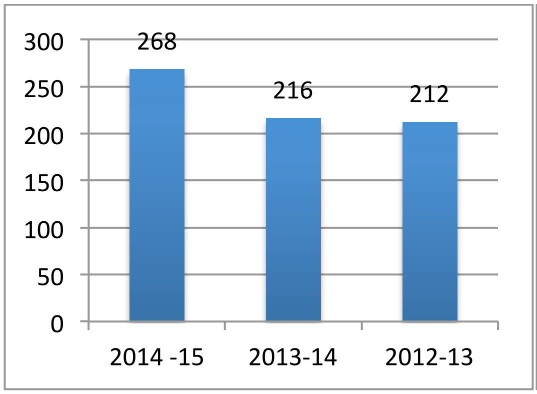

Figure 1. Student Enrollment

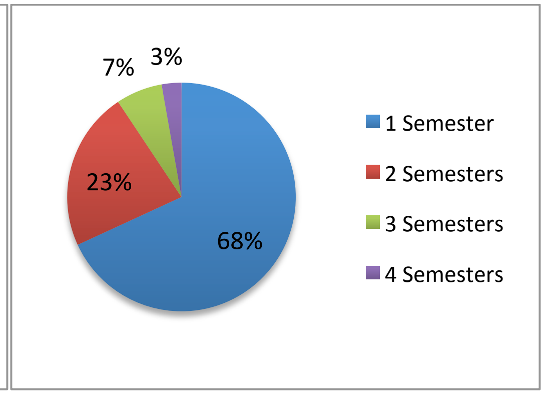

Figure 2. Percentage of Participants Enrolled for One or More Semesters

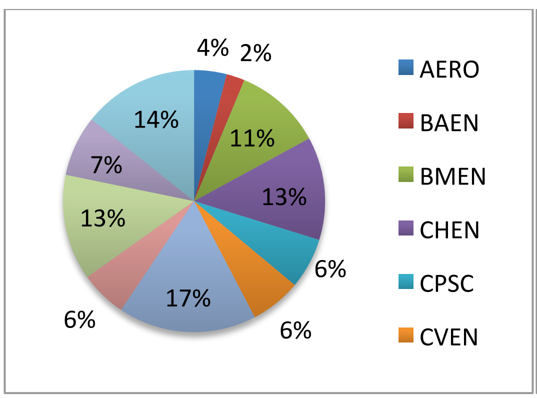

Figure 3. Engineering Majors of Participants (%)

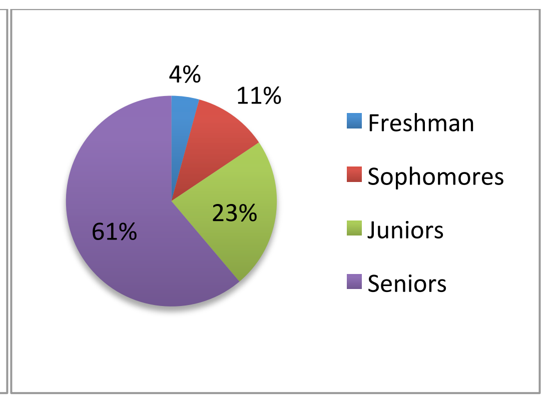

Figure 4. Classification of Participants (%)

Achievement of Student Outcomes

To evaluate the extent to which program participants achieved the desired students outcomes, participants were invited to participate in an online survey at the end of Fall 2013 and Fall 2014 semesters with participation rates of 25%, and 71% respectively. The complete set of survey questions is presented in Appendix A. Q1-Q5 questions are not discussed in the paper, because the institution will use these to address regional accreditation. Rather than develop their own questions, the authors used survey questions from a previous study of student achievement of outcomes [3]. In addition to the Likert Scale questions (Q1- Q30), students were asked also (Q31) to respond to the following questions: 1) what were the most valuable aspects of your experience with the program for your professional career?, 2) what were the benefits of your interactions with graduate students?, 3) if you are planning to purse graduate school, did participation in the program have an impact on your decision? The survey data have been grouped in six categories: (i) multidisciplinary teamwork, (ii) effective communication, (iii) understanding of impact of engineering on society, (iv) problem solving, and (v) design, (vi) research /graduate school.

Multidisciplinary Teamwork: To evaluate development with respect to multidisciplinary teams, participants were asked to rate their growth on their ability with respect to the following items:

- Develop ways to resolve conflict and reach an agreement in a group (Q18)
- Be aware of feelings of other members of the group (Q19)
- Listen to the ideas of others with an open mind (Q20)
- Work on collaborative projects as a team member (Q21)
- Be patient and tolerate the ideas or solutions proposed by others (Q25)
- Use discussion strategies to analyze and solve a problem (Q27)
- Recognize flaws in my own thinking (Q29)

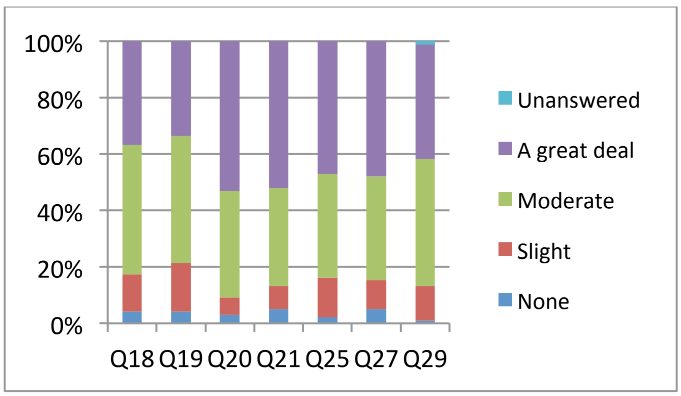

Figure 5. Student Self-reported Growth with Respect to Multidisciplinary Teamwork

As shown in Fig 5, more than 80% of participants rated their growth on all of the items that the authors related to teamwork as moderate to a great deal. Furthermore, more than 50% rate their growth as a "great deal" for Q20 (their ability to listen to others with an open mind) and Q21 (work on collaborative projects as a team).

In addition to the survey questions, participants were asked to respond to five prompts (Q31) about various outcomes of the project. In response to the prompts, one student said: "*collaborating with different people from different technical backgrounds is the biggest advantage of the program in giving students the ability to learn from people with different perspectives and gain a wider view of engineering*". Another student wrote: "*gaining valuable teamwork and management skills in a setting where the main objective was shared by many*".

Effective Communication: To evaluate development with respect to effective communication, participants were asked to rate their growth on their ability with respect to the following four items:

- Clearly describe a problem orally (Q15)
- Clearly describe a problem in writing (Q16)
- Explain my ability to others (Q17)

- Ask probing questions that clarify fact, concepts, or relationships Q(22)

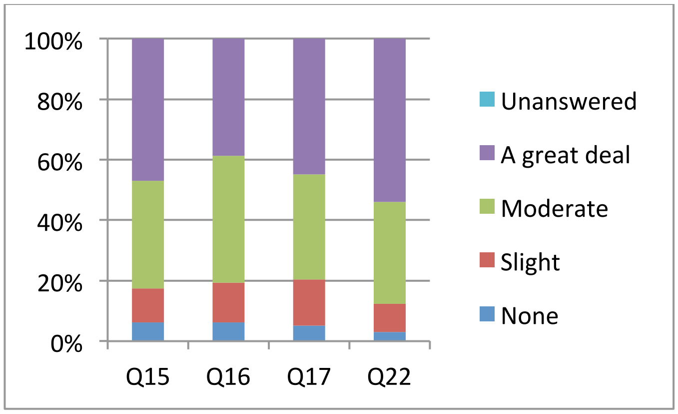

Figure 6. Student Self-reported Growth with Respect to Effective Communication

As shown in Fig 6, more than 80% of participants rated their grown in the listed areas of effective communication as moderate to "a great deal" while more than 50% of them rate their growth in their ability to ask probing questions that clarify facts, concepts, or relationships as "a great deal". In addition, participants recognized their development with respect to communication. One student wrote, "*some of the most valuable aspects of my experience with (the) program include sharpening my abilities to communicate engineering concepts effectively both in the form of a final report and through oral presentation. This is extremely useful skill to harness because there is no way to see your ideas turn to fruition if you cannot explain them to others*", another student wrote, *"I learned how to discuss different alternatives objectively with the rest of my group"*.

Appreciating Influences of Engineering on People: Participants were also asked to provide feedback on their growth in understanding of what engineering can contribute to society. There was only one survey question (Q6) that addressed this outcome. We looked for established scales for this outcome, but did not find one in time to incorporate in the survey. Fifty-six percent (56%) of participants rated their growth as "a great deal" and an additional 35% rated their growth as moderate. In the essay, one student wrote, "*the program is a wonderful opportunity to immerse ourselves in a real world project. It is amazing to think that we will actually be creating something that will benefit people around the world"*. Another student wrote, *"Interactions with faculty allowed me to see the bigger picture in solving engineering problems"*.

Problem Solving and Real World Applications: Participants were also asked to rate their growth on their ability to:

- Identify what information is needed to solve a problem (Q10)
- Apply abstract concept or idea to a real problem or situation (Q11)
- Divide problems intro manageable components (Q12)
- Develop methods that might be sued to solve a problem (Q13)
- Use established criteria to evaluate and prioritize solutions (Q14)
- Understand that a problem might have multiple solutions (Q26)

- Recognize contradictions or inconsistencies in ideas, data, images (Q28)
- Identify constraints on the practical application of an idea (Q30)

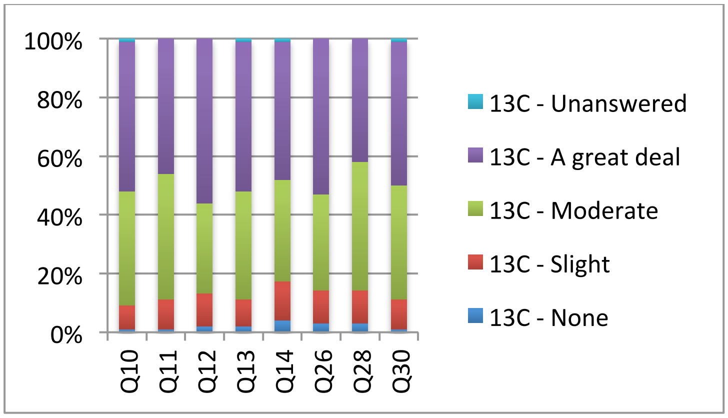

Figure 7. Student Self-reported Growth with Respect to Problem Solving and Real World Skills

As shown in Fig 7, 50% or more of the participants rate their growth as "a great deal" in Q10, Q12, Q13 and Q26 while more than 80% of them rate their growth as moderate or "great deal" on all questions. In the essay, one student wrote, *"I get to realize that real life problems are very different from those given in classes, because they are so open ended that there is no single solution"*. Another student wrote, *"the most valuable aspects of my experience with the program for my professional career would have to be the process of how to go about a project in real world"*. Another student wrote, "*The most valuable aspects of my experience with the program project is to have to find solutions to problems. I had to find what the problem I needed to solve was and then seek the people with the knowledge that I needed to and ask for help."*

Design: Participants were asked also about the impact of the program on their understanding of the design process. Since a significant percentage of participants are juniors, sophomores, and freshmen, better understanding on the design process at their level will have a positive impact on their performance in their capstone design courses. The survey asked participants to rate their growth in:

- Understanding of the language of design in engineering (Q7)
- Understanding of the process of design in engineering (Q8)
- Their ability to "do" design (Q9)
- Their ability to, after evaluating the alternatives generated develop a new alternative that combines the best qualities and avoids the disadvantages of the previous alternatives (Q23)
- Their ability to evaluate arguments and evidence so that strengths and weaknesses of competing alternatives can be judged (Q24)

Survey data, shown in Fig 8, indicate that more than 80% of participants rate their growth as moderate or great deal on all design questions. One student wrote: *"Being a part of the design process and seeing the project warp as we pushed on through challenging problems was truly amazing"*.

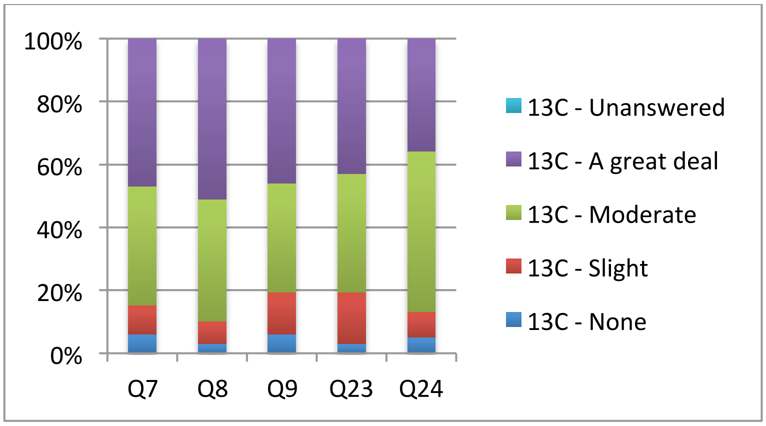

Figure 8. Student Self-reported Growth with Respect to Understanding of Design

Program Improvements

Participants were also asked about suggestions for further program improvement. These include, among others, improving the promotion of the program among students so that more students will become aware and participate, improving access to faculty facilities, improving interactions with faculty mentors and among team members for a more effective project outcome. These recommendations will be considered and addressed in the upcoming 2015-16 program.

Research & Graduate School

One of the goals for the program is to encourage students to see how greater knowledge of engineering may help them to address complex challenges with important societal and economic implications. One way they could improve their engineering knowledge would be to pursue a graduate degree. We did not obtain information about participants pursuing graduate degrees at other institutions; therefore, we can only report on participants' enrollment in graduate programs at this institution. Program data indicate that 12% of program participants who graduated with an engineering degree from our institution continued to graduate school at the same institution. This does not include those who left our institutions to pursue graduate school studies elsewhere. In the essay questions about impact of the program on their decision for graduate school, participants wrote about graduate school and also about the impact of the program on their understanding of research: *"It has been an excellent reminder that research does not have to be done in glamorous labs…research is not about taking shocking new steps but about gradually moving towards the state of the art"*, *"Helped me see what research can do to solve important problems. It has opened my eyes to the possibilities of a career in research"*, *"After this, I am more inclined to pursuing a graduate degree. It helped me see a different side of research with practical applications which I only thought possible in industry"*. *"I was able to see that the graduate students were, in fact, people who were simply interested in, and excellent at, engineering. It was a refreshing prospective"* and *"I was able to see that research was not merely as* *boring as I had been led to believe it was".* Finally, another student wrote, "*I feel the program has inspired me to create, I have now begun my own microcontroller project thanks to the things I learned in this class. The senior mentors were very useful thanks to their large pools of knowledge and experience. I would be interested in pursuing a STEM degree in graduate school. This program helped me rediscover the beauty in engineering".*

Assessment Fall 2013 vs. Fall 2014

Since the program is in the early years of development, authors were interested in evaluating the extent to which the program is improving. Therefore, they compared student feedback from Fall 2013 to Fall 2014. Overall, 41 out of 120 students completed the Fall 2013 survey and 104 out of 146 students completed the Fall 2014 survey. Figure 9 shows the percentage of students who responded "moderate" or "great deal" in questions Q6 thru Q30 for both Fall 2013 and Fall 2014 and it indicates that responses follow similar patterns for both semesters across questions Q6-Q30. Unfortunately, the responses do not reveal significant improvement. This will be addressed in future implementations of the program. In addition, authors would like to investigate responses from students participating in the program in spring semesters. Since all projects are established for the academic year, during spring semesters the program has a number of returning students with experience on the particular project from the previous fall semester and it is anticipated that they will have a positive impact on the student experience with the project.

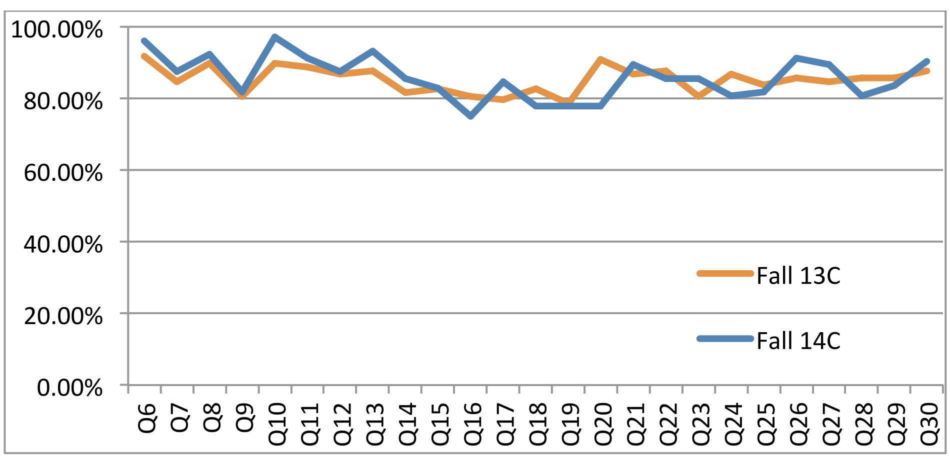

Figure 9. Survey for 2013 fall and 2014 fall.

Conclusions

Program implementation has been very successful to date. First, authors were concerned about how many students would be interested in participating. As shown in Fig 1, over 200 students have chosen to participate each year. Although the number of participants declined from year 1 to year 2, the number in year 3 was roughly the same as year 2. Therefore, there is sufficient student interest in the program. Second, student self-report data indicates that students can recognize their growth with respect to five important attributes for engineering graduates: multidisciplinary teamwork, effective communication, understanding of impact of engineering o society, problem solving, and design. Overall, more than 80% of participants rate their growth as "a great deal" or moderate on five attributes. Finally, student teams get an opportunity to publicly present their work at showcase held annually by the college of engineering. Reports from people from outside the college who viewed student presentations have been very encouraging.

Acknowledgements

Authors have received IRB approval for this study. The authors gratefully acknowledge support for the program that has been provided by the university.

Appendix A – Survey Questions

Skills / Knowledge	Question
Lifelong Learning	Q1. This semester I have explored topics in depth because I am interested in the subject
Lifelong Learning	Q2. In my courses this semester I have taken opportunities to expand my knowledge, skills, and abilities beyond just completing required work.
Lifelong Learning	Q3. Inspired by knowledge gained in my classes this semester, I have sought additional information
Lifelong Learning	Q4. I have connected what I learned in one course to another course and/or to my personal experiences.
Lifelong Learning	Q5. I tend to think deeply about my experiences inside and outside the classroom.
Appreciating Influences of Engineering on People	Q6. I rate my growth in understanding of what engineering can contribute to society as:
Design	Q7. As a result of my involvement in the Program, I rate my growth in understanding of the language of design in engineering as
Design	Q8. As a result of my involvement in the Program, I rate my growth in understanding of the process of design in engineering as
Design	Q9. As a result of my participation in the Program, I rate my growth in my ability to "do" design as
Problem Solving and Real World Applications	Q10. As a result of my involvement in the Program, I rate my growth in my ability to identify what information is needed to solve a problem as
Problem Solving and Real World Applications	Q11. As a result of my involvement in the Program, I rate my growth in my ability to apply an abstract concept or idea to a real problem or situation as
Problem Solving and Real World	Q12. As a result of my involvement in the Program, I rate my growth in my ability to divide problems into manageable components as

Applications	
Problem Solving and Real World Applications	Q13. As a result of my involvement in the Program, I rate my growth in my ability to develop several methods that might be used to solve a problem as
Problem Solving and Real World Applications	Q14. As a result of my involvement in the Program, I rate my growth in my ability to use established criteria to evaluate and prioritize solutions as
Effective Communication	Q15. As a result of my involvement in the Program, I rate my growth in my ability to clearly describe a problem orally as
Effective Communication	Q16. As a result of my involvement in the Program, I rate my growth in my ability to clearly describe a problem in writing as
Effective Communication	Q17. As a result of my involvement in the Program, I rate my growth in my ability to explain my ability to others as
Multidisciplinary Teamwork	Q18. As a result of my involvement in the Program, I rate my growth in my ability to develop ways to resolve conflict and reach an agreement in a group as
Multidisciplinary Teamwork	Q19. As a result of my involvement in the Program, I rate my growth in my ability to be aware of feelings of other members of the group as
Multidisciplinary Teamwork	Q20. As a result of my involvement in the Program, I rate my growth in my ability to listen to the ideas of others with an open mind as
Multidisciplinary Teamwork	Q21. As a result of my involvement in the Program, I rate my growth in my ability to work on collaborative projects as a team member as
Effective Communication	Q22. As a result of my involvement in the Program, I rate my growth in my ability to ask probing questions that clarify fact, concepts, or relationships as
Design	Q23. As a result of my involvement in the Program, I rate my growth in my ability to, after evaluating the alternatives generated, develop a new alternative that combines the best qualities and avoids the disadvantages of the previous alternatives as
Design	Q24. As a result of my involvement in the Program, I rate my growth in my ability to evaluate arguments and evidence so that strengths and weaknesses of competing alternatives can be judged as
Multidisciplinary Teamwork	Q25. As a result of my involvement in the Program, I rate my growth in my ability to be patient and tolerate the ideas or solutions proposed by others as
Problem Solving and Real World Applications	Q26. As a result of my involvement in the Program, I rate my growth in my ability to understand that a problem may have multiple solutions as
Multidisciplinary Teamwork	Q27. As a result of my involvement in the Program, I rate my growth in my ability to use discussion strategies to analyze and solve a problem as
Problem Solving and Real World Applications	Q28. As a result of my involvement in the Program, I rate my growth in my ability to recognize contradictions or inconsistencies in ideas, data, images, etc. as
Multidisciplinary Teamwork	Q29. As a result of my involvement in the Program, I rate my growth in my ability to recognize flaws in my own thinking as
Problem Solving and Real World	Q30. As a result of my involvement in the Program, I rate my growth in my ability to identify the constraints on the practical application of an idea as

Applications	
	Q31. Essay Questions: What were the most valuable aspects of your experience with the Program project for your professional career? What were the benefits of your interactions with the graduate students? Are you planning to pursue a graduate degree? If you are planning to pursue a graduate degree, did your participation in the program have an impact on your decision? What were the benefits of your interactions with faculty?
	Q32. What was the size of your team?
	Q33. To which of the following do you think your team would have benefited by having access? Please check all that apply.
	Q34. What improvements in the Program would you propose to make it more valuable to undergraduate students

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