AC 2011-2202: A MODEL FOR MULTIDISCIPLINARY EXPERIENCES FOR UNDERGRADUATES THAT PROMOTES RETENTION AND PIPELINE TO GRADUATE SCHOOL

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The Space Engineering Institute: A Multidisciplinary and Sustained Engineering Community Experience for *All* Engineering Students

Introduction

Advances in science and engineering are essential for ensuring US economic growth and national security. Attracting students from underrepresented groups into engineering and retaining to degree completion can increase the pool of qualified engineers entering the US workforce, promote social equity, and support the US economy in a global market. The Space Engineering Institute (SEI) was established in 2003 at the University as a partnership with the NASA Johnson Space Center targeting underrepresented groups. The SEI focus is to provide engineering experiences, improve graduation rates, and increase the pipeline to graduate school.

The SEI approach seeks to engage undergraduate engineering students in team projects that are multidisciplinary and multi-level (freshman to seniors) with faculty, graduate students, and NASA engineers serving as mentors. Students apply to the program and are selected based on their engineering majors and academic records. The SEI participants receive no class credit but they receive wage compensation. The program requires students to work on the team project ten hours per week, maintain a minimum GPR of 2.75, and receive satisfactory team-performance evaluations by the mentors at the conclusion of each semester.

Each team project is defined so that the research conducted by the student group is associated with a NASA specific technical need and guided by a NASA mentor. Our survey data reveals that participating students value the notion that their project is a "real" engineering problem. The SEI model has demonstrated excellent retention of the students in engineering with a graduation rate of above 70% (SEI cohorts of 2006 through 2009) compared to a 57% persistence in engineering after eight semesters (Ohland et al., 2008). This graduation rate is especially significant because SEI involves high percentages of ethnic minorities and females. The 2006 SEI cohort included 40.8% ethnic minorities and 70.8% females. Similarly, the 2007 through 2009 SEI cohorts included 29.4%, 23.5%, and 48.3% ethnic minorities and 64.71%, 70.59%, and 41.38% females respectively. Besides the increased graduation rates, it was observed that more than 20% of SEI 2007, 2008, and 2009 cohorts sought advanced degrees. These students reported that their early involvement in research and their interaction with the graduate student mentors had an impact on their decision to pursue a graduate degree.

In 2009-10, the SEI included ninety (90) students from four university campuses. The group represented nine (9) engineering departments and all four undergraduate levels (freshman to senior). Based on the success of SEI, a new program, Multidisciplinary Experiences for Undergraduates (MEU), was established in fall 2010 with focus to expand the SEI program beyond space exploration and include projects from a wide range of engineering sectors. Currently, team projects on power grid reliability and probabilistic risk assessment are offered to undergraduate engineering students at the university. In this paper, the authors will discuss the SEI approach, the retention data, student survey results, and the lessons learned that will provide insights to others who are interested in implementing a similar model at their institutions.

Theoretical Framework

Engineering majors leaving the field is a common problem across the US campuses. Among the reasons reported as engineering majors' reluctance to remain in engineering was "the lack, or loss of interest in science" and "the belief that non-STEM majors hold more interest, or offer better education" (Seymour, 1995). The lack of student interest or loss in their excitement to pursue engineering as future career options can be associated with their learning experiences in undergraduate courses.

Courses offered in undergraduate engineering programs can be highly technical and content knowledge oriented. Curriculum is often designed around the knowledge of the field with a primary intention to familiarize the students with the content knowledge. Basic courses in mathematics and sciences may not capture implications to engineering design or what engineers do in their practices. Most undergraduate courses offered across the majors are delivered in a teacher-centered fashion with many students receiving a lecture in a crowded classroom. The learning objectives in these courses are to help students acquire the skills and knowledge necessary to perform the tasks and practices related to their majors. Crowded classrooms and primarily teacher-centered instructions are cost and time effective to lecture many students at once, however they are not effective to keep students' interest in their majors. This is particularly true for the engineering majors.

There are efforts to cultivate more student-centered learning pedagogies in higher education (Bransford, Brown, and Cocking, 2000; McKenna, Yalvac, and Light, 2009). Transforming engineering education context from a teacher-centered orientation to a learner-centered orientation is a common interest in engineering education research. Group work, formative assessment, contextualized instruction, use of peer review and self-reflective tools, and out-of class collaborations are some learning-centered instructional strategies (Bransford, Brown, and Cocking, 2000; Yalvac, Smith, Hirsch, and Troy, 2007; Yalvac, Smith, Hirsch, & Birol, 2006). Nevertheless, in class learner-centered instructions have some limitations. Partly because of the institutionalization of engineering education and partly because of the traditional undergraduate education, learner-centeredness is limited by the course of a semester and not sustained over the students' programs of study. A typical undergraduate course runs only a semester. After the semester is over; students do not continue working on their projects. The assessment and/or the evaluation of the projects are completed by the end of the semester and students neither receive credits, nor can they be accountable for it, after the course is over. A typical course activity is constrained by time and the course learning objectives. These constraints limit the potential impact of the learning-centered pedagogies on students' developing interests, life-long learning skills, and retention in engineering.

Engineering students need more practical, first-hand experiences in their undergraduate years. Interning in industry is one way to give this first-hand experience to the students. However for the engineering students to intern, they often need to be upper division students in their program of studies. The timing of the professional experience students receive as they intern is counterproductive to the efforts to retain engineering students in their early college years. The majority of the college students transfer from one major to another during the first years of their college education and students who leave engineering are often do so without any first-hand and experiential engineering professional experience (Ohland et al., 2008). It is apparent that engineering students early in their program deserve to learn about engineering profession in addition to learning the technical and the scientific knowledge of their discipline. The program we describe in this paper is particularly designed to involve students from any levels (from freshman to senior) and keep their involvement over multiple semesters, ideally until they graduate.

It is more difficult for students to remain in engineering majors if they haven't been "challenged academically and/or *if they* lack specific course offerings such as calculus, or advanced placement science classes" in their K-12 education (Reichert and Absher, 1997, p.250). Traditionally underrepresented student groups fall into the not academically challenged category and/or lack the specific course offerings in their preparation for college. After an extensive review of the summer bridge programs across the US campuses, Reichert and Absher (1997) maintained that the way students learn and the way faculty teach might be contributing to the reason that women and minority students are less likely to stay in engineering programs during the course of their undergraduate education. Summer bridge programs and supplementary course offerings can help support the underrepresented minority students early in their undergraduate levels, however more systematic and effective pedagogies should be designed and implemented during their program of studies. Reichert and Absher (1997) noted that 50% retention rate is the desired threshold for any institution to aim to achieve.

The SEI Approach

The SEI program was designed to engage undergraduate engineering students, starting at their freshman year, in team projects being mentored by the NASA engineers and faculty. Each team includes six to eight undergraduates from several engineering majors and represents different classifications (freshman to seniors). Such a team composition allows for two-dimensional learning; learning above their skill level by interacting with upper division students within their major and learning outside their major by interacting with students from other engineering majors. Each team is assigned a graduate student mentor who supports the team on both technical and project management issues. In addition, the graduate mentor serves as a role-model for the students and encourages them to explore pursuing advanced degrees. The faculty interacts with the team through weekly meetings. The NASA mentor interacts with the team through weekly reports, mid-semester comprehensive technical reports, monthly teleconferences, visits to NASA, and end of semester technical presentations.

Students who join SEI and meet the academic and team performance requirements are encouraged to remain in the program for multiple years. Of the students who joined SEI as incoming engineering freshman in the fall 2002 to fall 2005, 30% remained in the program for one year only (freshman), 30% remained for two years (freshman and sophomore years), 21% remained for three years, 13% for four years, and 5% were still involved with SEI after four years.

The goals of the program were defined as:

- Target students from underrepresented groups
- Improve student participant retention in engineering

- Provide experiential learning opportunities for participants to enhance their engineering education
- Encourage participants to strive for high quality technical output
- Encourage participants to explore opportunities for advanced degrees

The SEI has demonstrated positive outcomes in each of the above goals as published before (Weitz and Lagoudas, 2009). These include recruitment of high percentages of ethnic groups and females into the program, increased graduation rates, excellent technical output by the students, and significant numbers of participants pursuing advanced degrees. This paper presents detailed responses of student participants on a recent survey that provide further insight on the value of the program to undergraduates.

Program Institutionalization

The SEI participants receive wage compensations for their participation in the program. Hence, the program requires financial resources for its sustainability. However, because of the positive outcomes demonstrated, we explored opportunities outside the NASA and the space exploration community. We were able to acquire funds from several sources, for example, Texas Workforce Commission, US Air Force, and Boeing. The team supported by the Texas Workforce Commission worked closely with South Texas Project (STP) on a heat transfer problem associated with the cooling of the Electrical Auxiliary Building at STP. The collaboration between the student team and STP was very effective. The student team presented their technical work at the 2009 International Conference of Nuclear Engineers (ICONE) in Belgium and at the 2010 ICONE in China (Hardy, King, Bigelow, ICONE18, 2010). The student team working with the US Air Force developed Matlab models for thermal analysis of small satellites under high heat loads. The team presented their project at the 2010 Small Satellite Conference in (Do we know where this happened?). The team funded by Boeing worked at the Land Air and the Space Robotics (LASR) laboratory. They developed calibration models for the Phasespace camera and designed and manufactured hardware for testing Unmanned Air Vehicle (UAV) prototypes.

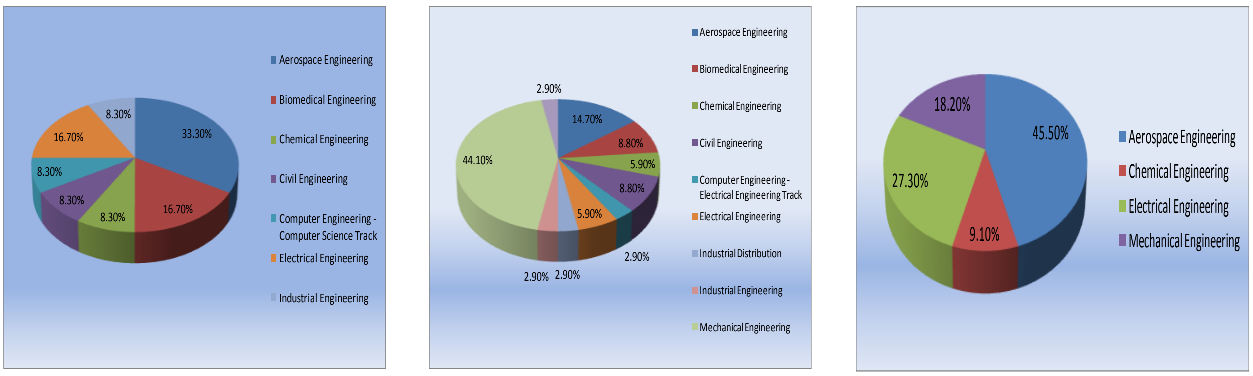
The Multidisciplinary Experiences for Undergraduates (MEU) was established in fall 2010 with focus to expand the SEI and offer undergraduates multidisciplinary team project experiences that cover a wide range of engineering applications. Currently, two MEU projects have been offered to students; a project on power grid reliability and a project on fire probabilistic risk assessment with focus on nuclear industry. Due to the limited funding, the MEU projects are offered to upper division students (juniors and seniors) for wage compensation while freshman and sophomores are invited to participate without any wage compensation. Furthermore, we are exploring options for students to participate in the MEU projects for course credit.

The SEI Student Participant Characteristics and Their Views of and Experiences with the Program

In 2009, 61 students participated in the SEI program in the main campus of a Research-I University. Twelve students were freshmen, 34 students were sophomore or juniors, and 15 students were seniors or graduating at the time we administered a SEI survey. The SEI survey was designed to capture students' demographics and their views of and experiences with the program activities.

Participants' Majors

The SEI participants in 2009 were coming from a diverse range of engineering majors. Figure 1 shows the number of the student participants in each of the three levels and their majors in percents.



Freshmen (N=12) Sophomore and Juniors (N=34) Seniors (N=15)

Figure 1. Engineering majors of 2009 SEI program participants.

Decision to Stay in Engineering

All SEI freshmen participants reported that the SEI experience positively influenced their decision to remain in engineering. Twenty-two sophomore and junior participants (66%) and twelve seniors or graduating students (80%) reported similarly that the SEI experience impacted their decision to remain in engineering. Only 12 sophomore/juniors (34%) and 5 seniors/graduating students reported otherwise.

When asked "please explain why the SEI did or did not impact your decision to remain in engineering" students reported positive outcomes of the SEI program. Below are some excerpts from participants' responses:

> *SEI showed me that despite what all the engineers complain about in class, many of the concepts that we are learning are actually relevant and will be useful when I get out into the real world.*
>
> *SEI has shown me that there are a lot of real world problems are not seen in a classroom and SEI has shown that engineers always have a place in the solution to these problems.*
>
> *The classes just give you work, but this gives you a project and something to be excited about.*
>
> *I was able to see what I should expect from my upper level classes and from majoring in Engineering. It was extremely beneficial because I now have a better idea as to what a job as an engineer entails.*
>
> *Freshman courses at [the enrolled program] have very little to do with engineering. SEI helped keep me focused and reminded me of why I am in engineering*

Preparation for a Post-graduate Role

When asked, "how do you believe the SEI will prepare you for a post-graduate role?" all freshmen checked "working on inter-disciplinary team" (Figure 2). This indicates that all freshmen were aware of the interdisciplinary characteristics of the SEI program. "Technical communication" was the second mostly reported skill freshmen believed that the SEI will help them develop. "Greater knowledge of subject-area" and "experimental methods" were the least reported helpful outcomes of the SEI participation. This indicates that one third of the SEI freshmen participants did not expect their SEI experiences to necessarily help them acquire subject-specific knowledge or methodological skills.

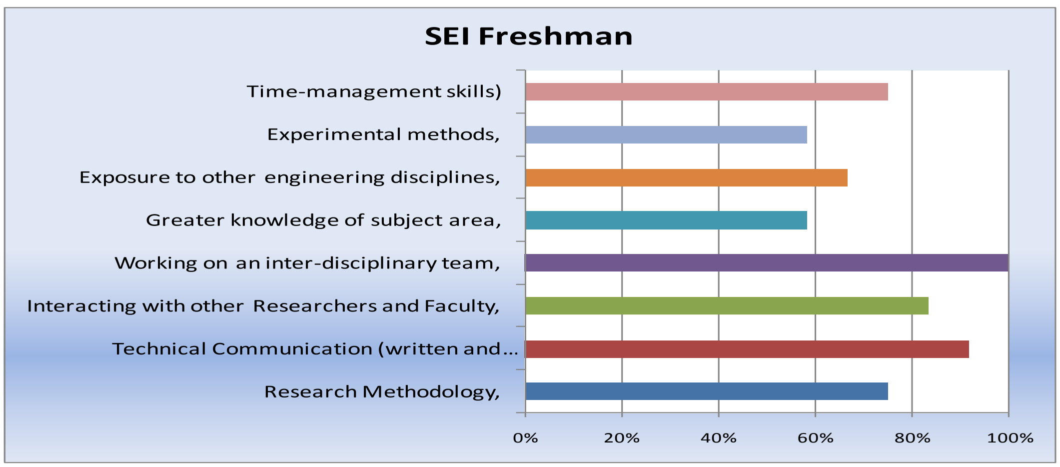


Figure 2. Post-graduate preperation areas freshmen reported that the SEI will help them.

When asked, "how do you believe the SEI will prepare you for a post-graduate role?" almost all (except one) sophomores and juniors checked "interacting with other researchers and faculty" (Figure 3). Technical communication was the second most checked response. "Exposure to other engineering disciplines" and "working on an inter-disciplinary team" were the next listed opportunities sophomores and juniors believed that the SEI participation helped them get prepared. Different from the freshmen, more than 60% of sophomores and juniors reported that experimental methods and research methodology were the two other areas the SEI would help them get prepared. "Greater knowledge of subject area" received more checks marks than "experimental method" that is also different from freshmen's responses.

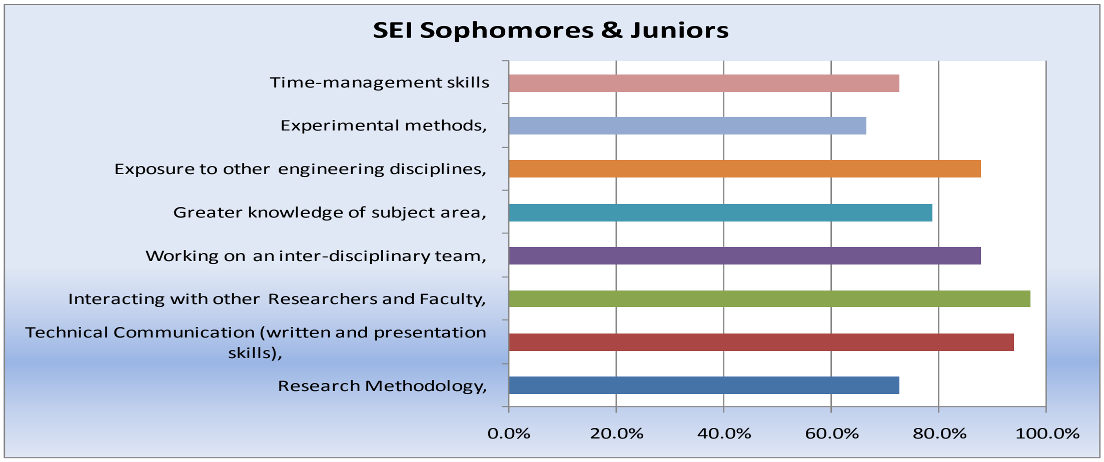


Figure 3. Post-graduate preperation areas sophmores and juniors reported that SEI helps them.

When asked, "how did the SEI prepare you for a post-graduate role?" seniors checked these four areas with equally high frequencies: "exposure to other engineering disciplines," " working on an interdisciplinary team," "interacting with other researchers and faculty," and "technical communication" (Figure 4). "Experimental method" was the least checked area, yet two third of the students reported that SEI prepared them in that area as well. It is apparent that as students become more seasoned, they valued the role of the SEI program in their preparation for a post-graduate role more.

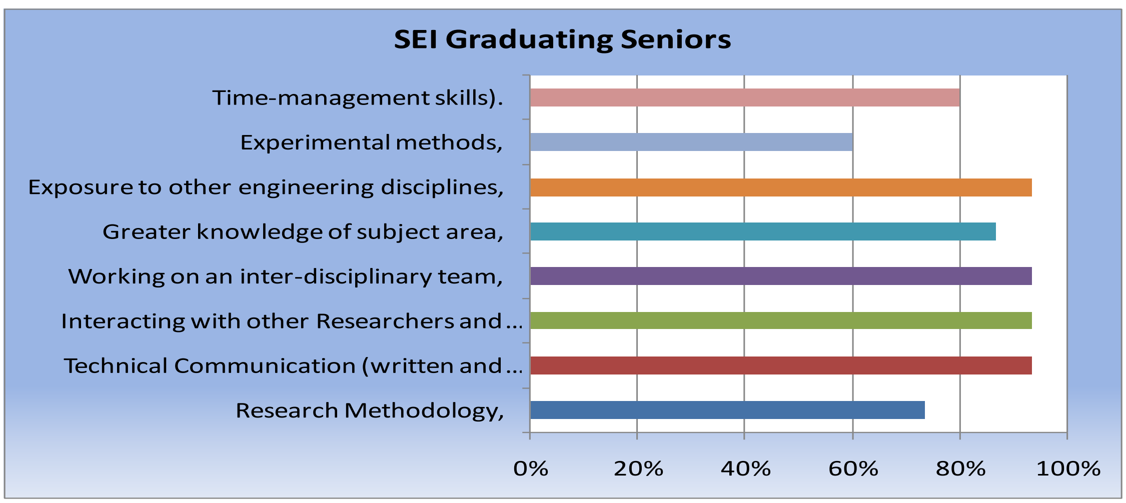


Figure 4. Post-graduate prepeation areas seniors or graduating students reported that SEI helped them.

The below excerpts futher illustrate the students' positive experiences with the SEI activities and the collabration oppurtunities it provided.

> *SEI experience has shown me how to work with a team of engineers, given me more experience in time management, and increased my knowledge and skills relating not only to my current major, but the majors and fields of my teammates as well.*

SEI has allowed me to gain some insight and knowledge from the older more experienced students in the engineering field.

SEI has definitely shown me that working as part of engineering team is something I want to do as a work experience.

It [SEI] has definitely be a positive experience. I feel like I have learned alot from being in this program.

The upperclassmen had already gone through everything I was about to go through and so the advice they gave was very beneficial.

Skill Levels or Ability after the SEI Experience

When asked: "After your experience in the SEI, how would you have ranked your skill level or ability in the following areas?" almost all participants reported positive (from some skill/ability to very significant skill/ability) in the below skill dimensions:

1. Knowledge of and ability to apply engineering and science fundamentals to real problems.
2. Ability to formulate and solve open-ended problems.
3. Ability to design mechanical components, systems, and processes.
4. Ability to set up and conduct experiments, and to present the results in a professional manner.
5. Ability to use modern computer tools in engineering.
6. Ability to communicate in written, oral, and graphical forms.
7. Ability to work in teams and apply interpersonal skills in engineering contexts.
8. Ability and desire to lay a foundation for continued learning beyond the bachelors' degree.
9. Awareness of professional issues in engineering practice, including ethical responsibility, safety, the creative enterprise, and loyalty and commitment to the profession.
10. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact

Ability to work in teams appeared to be the most significant skill SEI participants developed after the program activities. Student responses to the above ten questions are shown in Tables 1, 2, and 3.

Table 1. Senior students' ranking of the skill levels or ability they attained after the SEI experience.

	Very Significant Skill/Ability	Significant Skill/Ability	Some Skill/Ability	Minimal Skill/Ability	No Skill/Ability	Total	Mean	Std Dev
i. Knowledge of and ability to apply engineering and science fundamentals to real problems.	4	8	3	0	0	15	1.933	0.704
ii. Ability to formulate and solve open-ended problems.	4	6	5	0	0	15	2.067	0.799
iii. Ability to design mechanical components, systems, and processes.	2	8	3	2	0	15	2.333	0.9
iv. Ability to set up and conduct experiments, and to present the results in a professional manner.	3	10	2	0	0	15	1.933	0.594
v. Ability to use modern computer tools in engineering.	3	10	1	1	0	15	2	0.756
vi. Ability to communicate in written, oral, and graphical forms.	5	9	1	0	0	15	1.733	0.594
vii. Ability to work in teams and apply interpersonal skills in engineering contexts.	6	8	1	0	0	15	1.667	0.617
viii. Ability and desire to lay a foundation for continued learning beyond bachelor's degree.	4	8	2	0	0	14	2.133	1.246
ix. Awareness of professional issues in engineering practice, including ethical responsibility, safety, the creative enterprise, and loyalty and commitment to the profession.	4	6	3	1	1	15	2.267	1.163
x. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact.	3	6	5	0	1	15	2.333	1.047
Total	**38**	**79**	**26**	**4**	**2**	**150**	**N/A**	**N/A**

Table 2. Sophomores and junior students' ranking of the skill levels or ability they attained after the SEI experience.

	Very Significant Skill/Ability	Significant Skill/Ability	Some Skill/Ability	Minimal Skill/Ability	No Skill/Ability	Total	Mean	Std Dev
i. Knowledge of and ability to apply engineering and science fundamentals to real problems.	5	16	11	1	0	33	2.242	0.751
ii. Ability to formulate and solve open-ended problems.	4	22	6	1	0	33	2.121	0.650
iii. Ability to design mechanical components, systems, and processes.	6	10	14	2	0	32	2.375	0.871
iv. Ability to set up and conduct experiments, and to present the results in a professional manner.	11	12	8	2	0	33	2.030	0.918
v. Ability to use modern computer tools in engineering.	9	15	8	1	0	33	2.030	0.810
vi. Ability to communicate in written, oral, and graphical forms.	11	17	4	1	0	33	1.848	0.755
vii. Ability to work in teams and apply interpersonal skills in engineering contexts.	14	16	3	0	0	33	1.667	0.645
viii. Ability and desire to lay a foundation for continued learning beyond bachelor's degree.	12	15	4	0	0	31	1.742	0.682
ix. Awareness of professional issues in engineering practice, including ethical responsibility, safety, the creative enterprise, and loyalty and commitment to the profession.	11	12	10	0	0	33	1.970	0.810
x. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact.	8	11	12	1	0	32	2.303	1.075
Total	**91**	**146**	**80**	**9**	**0**	**327**	**N/A**	**N/A**

Table 3. Freshman students' ranking of the skill levels or ability they attained after SEI experience.

	Very Significant Skill/Ability	Significant Skill/Ability	Some Skill/Ability	Minimal Skill/Ability	No Skill/Ability	Total	Mean	Std Dev
i. Knowledge of and ability to apply engineering and science fundamentals to real problems.	3	3	5	0	0	11	2.182	0.874
ii. Ability to formulate and solve open-ended problems.	2	5	4	0	0	11	2.182	0.751
iii. Ability to design mechanical components, systems, and processes.	2	4	5	0	0	11	2.273	0.786
iv. Ability to set up and conduct experiments, and to present the results in a professional manner.	3	4	4	0	0	11	2.091	0.831
v. Ability to use modern computer tools in engineering.	2	7	2	0	0	11	2.000	0.632
vi. Ability to communicate in written, oral, and graphical forms.	3	5	3	0	0	11	2.000	0.775
vii. Ability to work in teams and apply interpersonal skills in engineering contexts.	6	3	2	0	0	11	1.636	0.809
viii. Ability and desire to lay a foundation for continued learning beyond bachelor's degree.	3	5	2	1	0	11	2.091	0.944
ix. Awareness of professional issues in engineering practice, including ethical responsibility, safety, the creative enterprise, and loyalty and commitment to the profession.	3	6	2	0	0	11	1.909	0.701
x. Awareness of contemporary issues in engineering practice, including economic, social, political, and environmental issues and global impact.	1	6	4	0	0	11	2.273	0.647
Total	**28**	**48**	**33**	**1**	**0**	**110**	**N/A**	**N/A**

Interest in Space Industry

Among the twelve (12) freshmen participants in the 2009 SEI program, eleven (11) of them indicated that they got interested in space industry because of their involvement with the SEI program activities. Below are some excerpts students provided:

> *SEI has most definitely influenced my plans. I thought about the space industry before coming to college, but I wasn't sure if it would be of interest to me. However, after my experiences in the SEI program, the space industry has become one of my top industry choices to possible work in.*
>
> *SEI has shown me how many different opportunities the space industry has.*
>
> *SEI has provided me with the opportunity to learn more about the space industry and what it takes to work in it.*
>
> *SEI gave me the window of opportunity to move a step forward to working for the space industry. I always wanted to work for the space industry but now with the help of SEI, I can make that dream come true.*
>
> *Last summer, I was sure that I wanted to work in national defense, but SEI has made the space industry option more interesting.*

The SEI's Impact on Future Career Plans

The SEI was effective to keep students interest in engineering. Below are some excerpts illustrating why the SEI effected students' decision to stay in the engineering field and/or choose it as future career goals.

> *SEI is a foothold for the beginning of my engineering career.*
>
> *SEI has shown me that engineering is a subject that I would like to continue my education in.*
>
> *SEI has shown me how continuing to graduate school can have a huge impact on future job opportunities.*
>
> *SEI has not necessarily helped me to know which career path is right for me but it has enabled me to learn which part of industry I am definitely not interested in.*
>
> *SEI has allowed me to see some of what the space industry is like and has made the space industry one of my top choices to possibly work in once I graduate from college.*
>
> *SEI has shown me that engineering is something I want to do as a career.*
>
> *Made me realize that engineering is the right field for me.*
>
> *Although I do not yet know what i specifically want to do following my graduation, thanks to SEI I do know that I want to continue pursuing engineering.*
>
> *SEI made my career plans less concrete as I am now considering a career in the space industry as well as national defense.*

Conclusion

The SEI has demonstrated that engaging engineering undergraduates —especially the traditionally underrepresented groups— in real world multidisciplinary team projects with industry/government agency involvement can assist in retaining them in engineering. Furthermore, the SEI participation enhances their college education by helping them develop engineering skills and skills associated with group work, leadership, and interdisciplinary teams. By providing these first-hand, experiential learning opportunities to our undergraduates starting at the freshman level, besides improving their retention and increasing the number of those graduating with an engineering degree, we are also providing them with valuable skills for their engineering careers. Ohland et al. (2008) noted that students' learning experiences in engineering programs are predominantly focused on content, while excluding broader personal development that is necessary for life-long learning. Programs like SEI engage students in social interaction and engineering practice early in their career by acculturating them in communities of engineers. Students who become familiar working with interdisciplinary teams for authentic engineering challenges are more likely to develop life-long learning skills. Programs like SEI can enhance students' learning experience in college that often lacks authentic and interdisciplinary engineering design projects.

The SEI program was intentionally designed to retain engineering students. The program did not aim to attract students from other majors or transfer them to engineering. Ohland et al. (2008), in their 17 year longitudinal and inter-institutional study, reported that the rate of students leaving engineering is actually not very different from the rate of students who are leaving their majors other than engineering during the first one to three years of their college education. However, the striking difference was in the rate of students who are not switching their majors to engineering. There were far fewer students who transferred to engineering from other majors than students who transferred to non-engineering majors from any discipline. Engineering programs thereby appear weak and not that attractive when it is time for students to decide on their persistent majors. Ohland et al. (2008) attributed the lack of attractiveness of engineering when students choose their final majors during their college education to the belief that "engineering requires a commitment prior to matriculating to college, beginning with high school preparation, college selection, etc." (275). If students haven't chosen engineering early in their programs, they rarely decide to choose it as a career. This weakens the number of students completing their degrees in engineering programs when compared to other majors. It is reported that the number of US engineering graduates is fewer now than it was twenty years ago in terms of absolute numbers and percentage of all college degrees (Ohland et al., 2008).

Efforts to keep student interest and motivation and improve their retention in engineering, is one way not to lose students already enrolled in the engineering programs. However, additional effort should be spent to attract students from other majors. Providing non-engineering college students with the opportunities to engage in authentic and interdisciplinary engineering projects similar to SEI may also show positive impact. The belief that engineering students should be good at mathematics, science, and other technical skills, but not necessarily in social interaction, creativity, complex problem solving, and effective communication, portrays a misleading picture of engineering. The interdisciplinary and challenge based characteristics of engineering can be conveyed to all students in their early college education. Future research may focus on designing and evaluating projects that involve not only students from engineering fields but also students from majors other than engineering.

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