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A Project Based Learning Engineering Course for a Summer Bridge Program

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Abstract

We offer a six-week summer bridge program (SummerStart) that is open to all entering first-year students in Engineering and Computer Science at Syracuse University. Historically, underrepresented minority (URM) students, women and first generation students have been recruited for this program and given scholarship support to attend. Compared to the entering first-year class, the SummerStart cohort typically has a significantly higher percentage of students who are at risk for attrition from Engineering and Computer Science. In this program in 2013, an existing engineering seminar course was transformed into a project based learning (PBL) engineering course, following previous success with curricular revision in a math course for the bridge program. The goals for the PBL course included: 1) establishing meaningful faculty-student interactions during the program, 2) introducing first-year students to real-world engineering projects and problem solving, and 3) enhancing the students' enthusiasm for engineering, effective teamwork, and attitudes towards persistence in Engineering and Computer Science. Our results show that the design of this course had a significant positive impact on students' interest in their majors, their attitudes about persistence in Engineering and Computer Science, and their performance in their first semester Engineering and Computer Science course.

Introduction

Retention of students in engineering and computer science undergraduate programs is a significant issue nationally.[1] Numerous studies have attempted to explain what causes some students to persist in engineering, and others to leave. A variety of academic and non-academic factors found to influence students' persistence include a sense of community, belonging, and collaboration in their engineering experiences, confidence in their academic abilities, the quality of faculty instruction and mentoring, their perspective on engineering's influence and value in society, sufficiency of pre-college preparation, and the difficulty of courses early in the engineering curriculum.[2-5] In general, women and underrepresented minority students are less likely to persist in engineering.[6] Reports also indicate that the persistence of women and underrepresented minority students in engineering may be adversely affected to a greater degree by their experiences within the engineering climate than their majority male counterparts. Here "climate" indicates perceptions of student belonging and interpersonal interactions between student peers, students and faculty (both in and out of the classroom), and individual compatibility with pedagogical styles in their classes.[2,7] An undesirable climate also has the greatest impact on student retention in the first years of engineering study.[8] Most students who leave engineering do so within the first two years from matriculation,[6] and students' self-reported desire to continue engineering, which is correlated to their persistence, declines on average about two semesters prior to actually leaving,[9] while disengagement from engineering-related courses is higher in non-persisting students[10].

Engineering programs can positively affect many of these influences on student retention by improving the engineering climate and implementing varied teaching strategies. For instance, the use of student-active pedagogies can increase feelings of belonging among students who are not traditional lecture learners[7] while simultaneously enhancing collaboration between peers and potentially easing the difficulty of the engineering curriculum for some students. Strategies that have been found to be effective for learning in engineering classrooms and promoting community-building amongst students include cooperative learning activities, model-eliciting activities, problem-based learning, inquiry-based laboratories, and learning communities.[3] The use of student self-assessment tools can help students to increase self-efficacy and confidence in their engineering-related abilities.[11] Many universities are currently utilizing multi-pronged approaches that include improvements to mentoring and academic advising, the development of a community of belonging, and improvements to teaching in the first two years in order to successfully increase retention in engineering.[12]

A 2012 ASEE report entitled, "Going the Distance: Best Practices and Strategies for Retaining Engineering, Engineering Technology, and Computing Students" highlights seven key themes of successful student retention strategies: 1) focus on student learning through tutoring and mentoring; 2) student programs and financial aid; 3) student academic enrichment programs; 4) student research and work experience; 5) curriculum and class enhancements; 6) institutional and educational research; and 7) change in institutional policy and faculty development.[12] Summer bridge programs are one of the strategies that fall under student and academic enrichment programs. Summer bridge programs are typically designed to help students transition from high school to the rigors of college by developing study and time management skills, orientation to university and college resources, and exposure to college level coursework and faculty.[13] Historically, summer bridge programs have focused on minority and low-income students, who are perceived to be 'at-risk' for attrition from their academic program or from university level study.[14,15] This has been the approach at our institution, where typically between 5-8% of the entering engineering and computer science cohort elect to enroll in a six-week, residential, summer bridge program. While our bridge program is open to all entering first year students, at-risk students are typically targeted in the marketing of this program and offered scholarships to attend. During the summer bridge program, students are housed together on campus and enrolled in a math course, a writing course or a social science/humanities course, and an engineering seminar.

Several curricular revisions have been made within our SummerStart program over the past five years. In 2009, we collaborated with a faculty member in Mathematics and Math Education to design a new math course for our summer bridge program. This course replaced a traditional course in pre-Calculus or Calculus I and allowed all engineering and computer science students to have a unified experience in math. The course was designed to prepare students in the bridge program to succeed in their first semester math course by teaching problem solving skills in the context of math and engineering, through hands-on modeling activities around the central mathematical theme of average rate of change. The impact of this course on student performance in their first math course of the fall semester has been remarkable, closing a previous full letter grade gap between Summer Start participants and their non-Summer Start peers.[16]

Building on the success of the curricular change in math, we next sought to modify the engineering seminar course. This course was previously coordinated by student services staff members in the college and was designed to teach time management and study skills, introduce students to the various engineering disciplines, and orient them to the various support services offered within the College of Engineering and Computer Science and across the University. The survey-style seminar course included presentations by many faculty and staff over the course of the bridge program, but did not contain any significant engineering content or multi-day interaction with faculty members. The frequency and quality of faculty-student contact, both in and out of the classroom, has been shown to impact student motivation and involvement[17] and is a strong predictor of success for at-risk students from under-represented groups[18]. Thus, we wanted to take advantage of the summer bridge program as a place where at-risk students could begin more meaningful interactions with faculty members in the college. We also wanted to build upon another best practice recommended in the ASEE report in the area of curriculum and class enhancements, namely integrating projects into classes. In 2013, the summer bridge program seminar course was transformed into a new project based learning (PBL) engineering course with the goals of: 1) establishing meaningful faculty-student interactions during the program, 2) introducing first-year students to real-world engineering projects and problem solving, and 3) enhancing the students' enthusiasm for engineering, effective teamwork, and attitudes towards persistence in Engineering and Computer Science.

Data presented in this paper will demonstrate the degree to which we were able to accomplish the aforementioned goals of this course in the two years that it's been taught. These goals are each aimed at important academic and non-academic factors that contribute to student persistence. We have also studied the effect of the change in pedagogical approach, from a survey-style seminar course to a PBL format, on several dimensions of student performance in their first semester including the grade in their first engineering course and their semester GPA.

Course Design and Projects

The new PBL course was developed around a series of four, week-long projects, each designed and directed by a full-time faculty member in the College of Engineering and Computer Science. The course has been taught with this structure for the past two summers (2013 & 2014). The course ran for six weeks and met four days a week, for 75 minutes per class period. The first week of the course was used to introduce the students to each other, practice teamwork, and make students aware of college and university-wide resources to support their success. Weeks two through five were devoted to the projects. The final week of the course was devoted to group presentations on the various engineering projects. Each department in the College contributed one project each year, thus spanning the different disciplines that students can major in and giving the students some knowledge about different types of engineering. The participating faculty were selected based on their expertise, experience, willingness to work with first year students, and their openness and approachability. An undergraduate teaching assistant was hired to support the faculty and SummerStart students each year. Three of the four projects were taught both years, by the same faculty. One project had to be changed the second year, due to the departure of the contributing faculty member from the University. A brief description of each of the projects is included here:

<u>Electrical Engineering: The Vampire Power Diaries (2013 & 2014)</u>
In this project, students learned about the power that is consumed through the operation of personal electronics (e.g. cell phones, laptops, tablets) and small appliances that they use in their daily lives. They used portable devices to measure power consumption and tracked this over the course of the

week. They used this data to determine power consumption during different operational states of devices, for example the power consumed during charging of a cell phone versus after charging is complete and the phone is still plugged in. Students used graphing and analysis techniques to compare across different students' measurements, devices, and operational conditions.

Civil Engineering: Bridging the Gap (2013 & 2014)
Students worked in teams to explore different bridge designs and to build bridge trusses using model materials. Once built, load cells were used to measure the forces in various members of the bridge structure under a static load. Students graphed their data to visualize which members of the structure were under tension, which were under compression, and the magnitude of these forces. Analysis was performed to compare the performance of different bridge designs and to understand how failures can and do occur.

Mechanical Engineering: Working Backwards: Reverse Engineering as a Design Tool (2013 & 2014)
In this project, students were required to work in teams to methodically disassemble a small consumer product. An emphasis was placed on understanding how the product worked and then reassembling it into working order. Small mixers and can openers were used. Students took extensive notes on the process, so as to discuss issues about learning from reverse engineering, the ethics of reverse engineering, and also issues on manufacturing decisions, design for assembly, and how they would communicate their findings to the manufacturer.

Biomedical Engineering: Nature's Graphics Card – Sensory Processing in the Brain (2013)
Students worked in teams to dissect earthworms and isolate the animal's central nerve cord and then externally stimulated the nerve cord electrically. Through use of oscilloscopes and data acquisition software, they were able to observe the response and characterize how the nervous system transmits signals. In a second activity, students went through several examples of human sensation versus perception, the difference between what information the senses provide and how that information is stitched together into perception of the world. Examples were performed associated with vision showing the limits of color vision; how the brain processes touch and balance; and human capacity for locating objects based on sound alone. The latter involved the students building their own electronic clicker devices to use as landmarks before navigating around an object blindfolded.

Biomedical Engineering: Biomaterials and Biomimicry: Reconstructing the Human Body (2014)
Students worked in teams to design a prototype composite scaffold for muscle replacement in a distal biceps fracture. The scaffold needed to mimic the mechanical properties of the natural tissue in the direction of highest applied force. The students were given nylon fibers, as a reinforcing phase, and allowed to choose the orientation of their fibers in different layers of the scaffold. They then tested their scaffolds in tension to determine the stress-strain profile of their composite and to study the effect of fiber orientation on the strength and strain-to-failure of their materials. Students presented their design rationale and discussed their results in class.

Data Collection

Participants in the 2013 and 2014 SummerStart programs were asked to complete an online survey at the end of their PBL engineering course. The survey was designed to assess the degree to which the students felt the course objectives were met and the impact that the projects had on several important attitudes related to student persistence. The response rate on the survey was 90.5% (19/21) in 2013 and 92% (23/25) in 2014.

Demographic data was also collected for all participants in the SummerStart program in 2011, 2012, 2013, and 2014. This included the gender, race/ethnicity, and citizenship status of each student. We also collected SAT scores (Math, Verbal and M+V), first semester GPA, and the final grades in ECS 101. ECS 101 is an Introduction to Engineering & Computer Science course that all first year students take in their first semester. Students are divided into small, discipline-specific sections, according to their major. None of the projects that were used in the summer bridge program were repeated in ECS 101 in the Fall. For statistical analysis, data were lumped into two groups reflecting the cohorts before the course redesign (2011, 2012) and the cohorts after (2013, 2014). Comparisons were made using t-tests for equal or unequal variance and data were determined to be statistical significant at p-values less than 0.05.

Results and Discussion

In 2011 and 2012, a total of 56 students enrolled in the Engineering and Computer Science summer bridge program. All of these students enrolled in and successfully completed the survey-style Engineering seminar course that was then offered. These students were a very diverse group, with respect to race and ethnicity. In 2011-12, 64.3% of the students enrolled in this program were under-represented minority students, with the majority of those being Black/African American (22/56 students, 39.2%). White students made up only 21.4% of these two cohorts and Asian students comprised 14.3%. In comparison, URM students only made up 16% of the entering cohorts of 2011 and 2012 in the entire College. The students enrolled in the bridge program in 2011-12 were 26.8% women, which was just slightly above the fraction of women in the entering cohorts of those two years. A vast majority of the summer bridge participants in 2011 and 2012 were U.S. citizens (89.3%) and native English language speakers. These data are summarized in Table 1.

Table 1. Demographic data for Summer Bridge Program participants in 2011-2014

	% Women	% White	% Asian	% URM	% US Citizen
2011-12	26.8	21.4	14.3	64.3	89.3
2013-14	43.5	13.0	45.7	41.3	58.7

In 2013 and 2014, a total of 46 students enrolled in SummerStart. All of these students enrolled in and successfully completed the new, PBL-based Engineering course. There were some significant demographic shifts between the cohorts of 2011-12 and the cohorts of 2013-14, within the bridge program. There was a very large increase in the number of Asian participants in 2013, where they comprised 57.1% of the total bridge program cohort. The percentage of Asian students in the program fell to 36% in 2014, but this was still more than double the representation of Asian students as compared to 2011 and 2012 (15% and 13.9%, respectively). The majority of these students were recent immigrants to the United States from China. This is also reflected in the significant drop in the percentage of U.S. citizens in the program, a decline from 89.3% to 58.7%. Most of these students had only had 1-4 years of instruction in English and were at various points of mastery in their language skills.

Another relevant demographic shift in 2013-14 was the increase in the percentage of women participants. This increased to 43.5% for the combined group, with women making up 47.6% of the 2013 cohort and 40% of the 2014 cohort of the summer bridge program. This is significantly higher than the fraction of women in these two Engineering and Computer Science entering cohorts, which was approximately 24%. The percentage of URM students dropped to 41.3% in 2013-14, but this is still significantly higher than the percentage of URM students in the entering cohorts those two years. These data are also summarized in Table 1. Additionally, 53% of the students in enrolled in the bridge program in 2013 and 2014 were first generation students. These data are not available for the 2011 and 2012 cohorts.

SAT data were analyzed for the four cohorts of interest, as an indicator of preparedness for college level study and to be able to compare between groups. These data are summarized in Table 2. The average combined math and verbal SAT scores for the 2011-12 and 2013-14 bridge program cohorts were 1107 and 1118, respectively, and were not significantly different. In comparison, the average combined SAT scores for the entering cohorts of 2011-12 and 2013-14 in the College of Engineering and Computer Science were 1195 and 1209, respectively. As expected, the average SAT scores of the bridge program participants are lower than the entire entering cohort, potentially indicating that these students are more at-risk academically. However, when the bridge program data were analyzed separately as math SAT and verbal SAT scores, there were significant differences. The cohorts of 2011-12 had significantly lower average math SAT scores (581 vs. 629, $p<0.05$) and significantly higher average verbal SAT scores (525 vs. 488, $p<0.05$), compared to the bridge program cohorts of 2013-14. The large increase in Asian, non-native English speakers, seems to account for this trend. These students had an average math SAT score of 695 and an average verbal SAT of 391. While these students would not be considered ‘at-risk’, solely based on their math SAT scores, their relatively weak English language skills are still a concern. This may impact their ability to fully understand college-level instruction, the development of peer-peer relationships with non-Chinese peers, and their extent of social integration with other students in the College of Engineering and Computer Science. We did observe some degree of social self-segregation within these groups of students and some difficulty communicating with their peers in the team-based PBL format. Therefore, we think it’s important to consider these factors and not assume a different level of preparedness for college level success in Engineering and Computer Science, solely based on math SAT scores.

In 2013 and 2014, students were surveyed at the end of SummerStart to assess the degree to which the projects in the course impacted their interest in engineering, their confidence in studying engineering in college, their level of comfort in interacting with faculty instructors, and their ability to work effectively in teams. Results showed that 64% (2013) and 83% (2014) of the students agreed or strongly agreed that the projects made them more interested in engineering. In 2013, 74% of the students agreed or strongly agreed that the projects made them feel confident about studying engineering in college. This measure increased to 85% of the students in the bridge program in 2014. SummerStart participants found the faculty accessible, as indicated by 92% (2013) and 85% (2014) of the students reporting that they felt comfortable asking questions in class. Finally, 84% (2013) and 90% (2014) of the students reported that their projects taught them to work effectively in teams. These data are shown graphically in Figure 1.

Table 2. Math and Verbal SAT Score Comparison for Summer Bridge Participants versus the full Engineering and Computer Science (ECS) Entering Cohorts

	Summer Bridge Program Participants			Entering ECS Cohorts		
	N	SAT M	SAT V	N	SAT M	SAT V
Fall 2011	20	564	544	401	634	555
Fall 2012	36	592	515	384	639	559
Fall 2013	21	641	464	389	645	564
Fall 2014	25	621	508	390	645	564

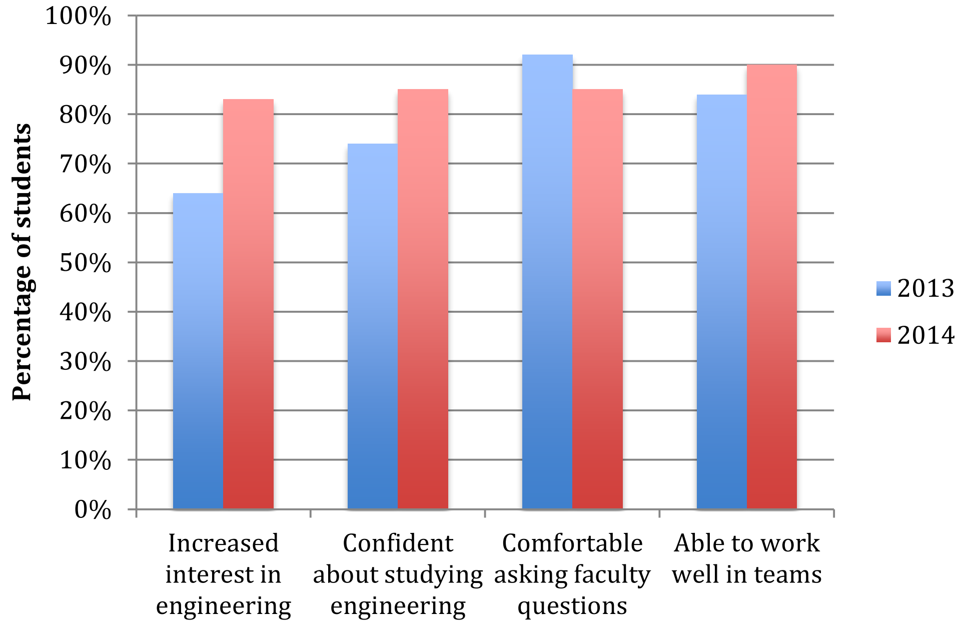

Figure 1. This data shows the impact of the PBL summer bridge course on students' attitudes towards engineering. Students were asked about the degree to which they felt that the projects in the course increased their interest in engineering and their confidence for studying it. They were also asked about their level of comfort in interacting with the faculty and working in peer teams. Responses here indicate the percentage of students who agreed or strongly agreed that the projects in the course influence them positively in these areas.

It is difficult, at this point, to study the long-term impacts of this course revision on student retention. However, there are some preliminary indicators that the positive impacts measured on student interest, confidence, student-faculty, and peer-peer interactions may give these students a boost in their first semester. All Engineering and Computer Science students enroll in ECS 101 in the first semester. We analyzed course completion rates and ECS 101 grades for the students who participated in the summer bridge program, along with the rest of the first year students in the College over the years 2011-2014 (Table 3). Before 2013, SummerStart participants had a significantly lower course completion rate (avg. 87.5%) and course performance (avg. grade of 2.84) in ECS 101 in the subsequent fall semester. After the implementation of the PBL course in the summer bridge program, the ECS course completion rate increased significantly to an average of 93.5% ($p<0.05$), approaching the course completion rate of 96.5% for the entire cohort. ECS 101 average grades for the SummerStart participants also increased significantly to 3.30 ($p<0.02$). We also examined first semester GPA for the bridge program participants. There was no effect of the PBL course on the first semester GPA of the bridge program participants. It is interesting to note however, that none of the students who participated in the summer bridge program in 2013 and 2014 have been suspended from the university due to poor academic performance. In comparison, 5 students from the SummerStart cohorts of 2011 and 2012 were placed on academic leaves by the end of their first year of enrollment.

Table 3. ECS 101 completion rates, grade performance and first semester GPA data by cohort for Summer Bridge Program participants and all first year students in Engineering and Computer Science.

	Summer Bridge Program Participants			**Entering ECS Cohorts**	
	ECS 101 completion rate	ECS 101 performance	First semester GPA	ECS 101 completion rate	ECS 101 performance
Fall 2011	80.0%	3.11	2.83	94.3%	3.30
Fall 2012	91.7%	2.71	2.76	95.3%	3.26
Fall 2013	95.2%*	3.30⁺	3.14	96.7%	3.44
Fall 2014	92.0%*	3.30⁺	2.80	96.2%	3.54

*ECS 101 course completion rates for the 2013 and 2014 cohorts (pooled) were significantly higher than the 2011 and 2012 cohorts ($p<0.05$)
⁺Average ECS 101 grades for the 2013 and 2014 cohorts (pooled) were significantly higher than the 2011 and 2012 cohorts ($p<0.02$)

In fall 2014, 18 of the 21 SummerStart students in the 2013 cohort were still enrolled in Engineering or Computer Science majors at the university. This first year retention rate of 86% is comparable to the entire entering cohort of 2013, despite the higher risk of attrition in this population of students. The first year retention rates for the summer bridge program cohorts of 2011 and 2012 were 85% and 86%, respectively. Therefore, there does not appear to be a major shift in retention as a function of this course revision. First year retention data for the SummerStart students of 2014 is not yet available. At the start of their second semester, all 25 participants were still officially enrolled in the College of Engineering and Computer Science. However, three of these students are no longer taking courses towards their engineering or computer science degree, indicating that they plan to transfer out of the college to another major at the university. This would yield a projected 1st year retention rate of 88% for this cohort. Two of these three had poor academic performance in their first semester, resulting in academic probation.

Conclusion

The Engineering seminar in our summer bridge program was transformed in 2013 from a survey-style course that oriented students to the engineering disciplines, College and University resources, and time management and study skills, to a project based learning course taught by full-time Engineering and Computer Science faculty members. The students were introduced to real world engineering projects and problem solving approaches, while working in small teams with direct peer and faculty interaction. Students in the PBL course indicated that their participation in the projects increased their interest in engineering, their confidence in studying engineering in college, their positive interactions with engineering faculty, and their ability to work effectively in teams. This translated into improved completion rates and performance for these students in their first semester Engineering and Computer Science course, as compared to their SummerStart peers from 2011 and 2012, before the course revision. Further follow-up with these students should be done to assess the longer-term impacts of this course on their retention and success in their engineering or computer science degree program.

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