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First-Year Engineering Courses Effect on Retention and Workplace Performance

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Abstract

Due to a drop in the number of students enrolling and persisting in engineering programs, there is currently a lack of qualified engineering graduates, which jeopardizes both the health of the U.S. economy and the security of the nation. This issue has led to the development and implementation of a variety of pre-engineering and first-year engineering experiences designed to recruit more students to engineering and to retain them once they have chosen to pursue a degree in engineering. At the University of Cincinnati, three common first year engineering courses were introduced during the 2012-2013 school year to provide students with hands-on experiences in engineering and a link between engineering and the required mathematics and science courses.

This paper builds on previously presented work, focusing on the impact of these courses on student performance and retention within engineering. A description of the first-year courses is provided as well as the lessons learned and changes made over the first 3 years of offerings. Data from course surveys will be discussed showing student perceptions of the courses and of the curricular modifications.

The main focus of this paper is on retention data and on student performance data while on cooperative education (coop). Retention data from the first offering of these courses was presented previously. Retention data from the second offering of these courses will be added to the previous data to better show the effect of these courses on student persistence within engineering after the first year as well as retention from the second to third years. Student performance data was gathered from student and employer evaluations completed at the end of coop rotations. All students are required to participate in the coop program beginning their sophomore year. Results from the first cohort of students to participate in both these courses and completed their first coop rotation is analyzed to understand the effects of the first-year courses on student preparation and performance, particularly related to professional skills and problem solving abilities.

Introduction

Engineering programs across the country have seen a significant decrease over the past several decades in the number of students both enrolling and persisting.[1-2] This has led to a lack of individuals with the necessary qualifications to fulfill the demands of industry within the United States.[3] A lack of qualified engineering graduates jeopardizes both the health of the U.S. economy and the security of the nation. As a result, a variety of new and innovative approaches have been employed to attract new students to engineering, especially individuals from underrepresented minority groups and women, and help them to persist to graduation.

Historically, a key reason that students leave engineering is the lack of engineering related experiences in the first year.[4] A common reason students pursue engineering is because they enjoy the process of creation and the ability to work with their hands. However, typical engineering curricula, up until recently, required students to complete a significant number of mathematics and science courses prior to beginning disciplinary coursework. These courses typically deal with abstract material with little engineering context. As a result, students end up believing that engineering courses will be similar to the mathematics and science courses and ultimately leave for other fields where applications can be seen much earlier in their academic career.[5]

One approach to address this issue has been the development and implementation of first-year engineering experiences, either through engineering specific courses or integrated curricula, to provide context and support for the mathematics and science courses taken during the first year and to provide students with engineering-related experience.[5] Use of these strategies has been shown to improve retention of students in engineering fields.[6]

The University of Cincinnati (UC) switched from quarters to semesters prior to the 2012-2013 academic year. The switch to semesters provided an opportunity to make changes to the first year curriculum, which previously included no common engineering courses taken by all of the engineering students. A set of three first-year engineering courses were introduced that were designed to provide students with a hands-on experience with engineering and with a link between engineering and the required mathematics and science courses. The three courses consist of an introduction to engineering course called Engineering Foundations and a two-course sequence called Engineering Models I and II, which introduces students to computing as a tool for solving engineering problems, through the use of MATLAB®. All three courses are required for all engineering and engineering technology majors, are 2 credit hours, and meet once a week for lecture (55 minutes) and once a week for recitation (2 hours). In a previously published paper at ASEE, it was shown that these courses had a positive impact on student retention from the first to second year.[7]

Another approach is to get students out into the workforce as early as possible to allow them to opportunity to experience the direct application of engineering in a real-world context. This practice is often referred to as cooperative education, or coop. At UC, students are required to complete four coop rotations during their academic career, starting with either the fall or spring semester of their sophomore year. Coop has been shown to improve both student performance and retention.[8-9]

In this paper, additional data will be presented on the impact of the first-year courses on student retention from the first to second years. Additionally, the impact of the first-year courses on student performance on the first coop experience will be explored through analysis of employer coop surveys completed at the end of each student’s rotation. The results of the first cohort of students to complete the required first-year courses under the semester system will be compared to the performance of prior cohorts of students, specifically focusing on the aspects addressed in the first-year courses of problem-solving and professional skills. In the next section, a description of the courses is provided.

Engineering Foundations

The Engineering Foundations course aims to introduce students to the types of activities engineers perform and provides information on the engineering degree programs. Students are introduced to several engineering disciplines through four hands-on experiments. The students work in groups of three to complete the experiments, which consist of bridge-building and analysis under static and dynamic loads; analyzing basic circuitry, including RC circuits and resistors in series and parallel; investigating the basic laws of thermodynamics through the use of Peltier devices as heat pumps and heat engines; and using solar cells to convert light into electrical energy and using fuel cells to generate electrical energy from the reaction of hydrogen and oxygen. Each of the experiments lasts for two weeks. A fifth experiment was added during the 2013-2014 academic year offering which required students to combine elements of the previous experiments and to explore topics of interest to them, such as designing a prototype for a solar-powered cooler, exploring the operation of a simple rectifier circuit, and designing and analyzing the performance of a fuel cell powered car.

In Engineering Foundations, students are also introduced to a number of professional skills, such as technical writing, communication, engineering ethics, and the engineering design process. Technical writing is covered by requiring the students to prepare laboratory reports for each of the four hands-on experiments. Communication is emphasized through a group presentation that requires the students to research one of the fourteen Grand Challenges[10] identified by the National Academy of Engineers and to present their findings to the class. Ethics is covered during a lecture that uses practical examples and role playing to emphasize the challenges in making ethical decisions in an engineering context.

As mentioned previously, the Engineering Foundations course is a 2-credit hour course which meets once per week for a 55 minute lecture and a 2 hour recitation period. In lecture, students are introduced to the content for the week's recitation activity. During the weeks devoted to the hands-on experiments, lecture is devoted to providing students with the associated content knowledge. Students then work in groups of 3 on the recitation activities. Undergraduate teaching assistants (TA) are employed to help students through the activities, with a ratio of approximately 10 students per TA. This frees the instructor to circulate among the students and help address misconceptions and reinforce content and skills discussed during lecture.

Engineering Models I and II

The other two courses, Engineering Models I and II, form a two-semester sequence. This sequence of courses serves two purposes: to introduce students to the computer as a tool for solving engineering problems and to provide context and applications for the mathematics and science material covered in other introductory STEM courses. In the Engineering Models I course, students are introduced to the computation package MATLAB® and shown how it can be used as a tool when solving engineering problems. The primary focus in Engineering Models I is the development of the computation skills and knowledge required for solving nontrivial engineering problems. During the course, students gradually progress from basic plotting and arithmetic operations through conditional logic, decision making, repetition, and data storage and analysis. Throughout, content is presented in such a way as to provide context for why the various concepts are needed, either by drawing on engineering examples or examples from mathematics and the sciences.

In the Engineering Models II course, the attention turns from developing computing proficiency to using MATLAB® in engineering applications and providing context to the other STEM courses required of the first-year engineering students. Here, students are introduced to statistics and data analysis, numeric differentiation and integration, applications of differentiation and integration, communications, basic mechanics, and system modeling. The course ends with a project requiring the students to work in groups to design a graphical user interface (GUI) that serves as a teaching tool for some topic that they learned in calculus, chemistry, physics, or a discipline specific engineering course. This project requires students to utilize the knowledge gained throughout the year as well as tie the computation skills developed to an application of their choosing which they have already experienced.

Impact on Retention

There was a sizable improvement in retention of first-year students in the 2012-2013 academic year when the university transitioned from the quarter to semester system and the three common courses were implemented and required for all incoming freshmen. While the retention rate for the second year under the semester system was not quite as high as the first, it is still well above the average of 72.6% for the previous ten years. The retention rates for the last twelve years are shown in Table 1.

TABLE 1: Retention Rates (Percent of Class Returning) from First to Second Year

2002 2003	2003 2004	2004 2005	2005 2006	2006 2007	2007 2008	2008 2009	2009 2010	2010 2011	2011 2012	2012 2013	2013 2014
72.6	73.6	70.5	71.4	75.2	75.0	76.5	73.2	60.5	74.2	77.3	76.5

One possible explanation for the increase in the retention rates from the 2011-2012 to the 2012-2013 academic years is that the minimum composite ACT requirement for admission was increased by one point. This requirement was then relaxed with the 2013-2014 academic year when the college adopted a holistic approach to admissions. However, if the credentials of the previous four incoming classes are compared, there is little difference in the quality of the student. The only noticeable difference is a slight increase in the average composite ACT score from the 2011 to 2012 cohorts, which corresponds to a similar jump in the average ACT math score.

TABLE 2: Incoming Class Qualifications

	2010 Cohort	2011 Cohort	2012 Cohort	2013 Cohort
Avg ACT Composite	26.94	26.95	27.38	27.38
Avg ACT Math	28.08	28.13	28.56	28.46
Avg High School GPA (unweighted)	3.56	3.56	3.59	3.58

There are a number of different factors at play when trying to understand the retention rates of first-year students. For instance, with the switch to semester, some modifications were made to the calculus sequence as well as the first-year chemistry and physics courses. However, given that the quality of the student entering the college has remained relatively steady over the past several years despite changes in admissions requirements, it would appear that the introduction of these courses has had a positive effect on student retention.

COOP Employer Survey Data

As mentioned previously, the engineering program at UC requires students to complete 4 coop rotations during their studies. Students begin their first coop rotation during their sophomore year. This provides a unique opportunity to assess the impact of curricular modifications on the performance of students in the one area that truly matters: the application of their skills and knowledge on the job.

At the end of each coop rotation, a survey is sent from the university's office of professional practice to the employers requesting feedback on each student's performance on a variety of work-related attributes. Responses are given on a 5 point Likert scale (1 = unsatisfactory, 2 = poor, 3 = satisfactory, 4 = good, 5 = excellent). The individual questions are shown in table 3.

The first cohort of students to complete the required first-year engineering curriculum finished their first coop rotation during the 2013-2014 academic year. To assess the impact that the new courses have had on student performance, the data for the class of 2017 (enrolled in 2012) was compared to the 2013, 2014, and 2015 classes. The class of 2016 was excluded due to the problems with the data as the first class to participate in coop under the semester system. Of the 41 questions asked of the employers, the responses for the questions in the communication, conceptual and analytic ability, and teamwork categories were focused on as these skills are specifically stressed throughout the first-year engineering courses. A comparison of the responses for these different areas is shown in figures 1-3. The bars represent the average response for each cohort.

TABLE 3: COOP Employer Assessment Instrument

Category	Question
Communication	Speaks with clarity and confidence
	Writes clearly and concisely
	Makes effective presentations
	Exhibits good listening and questioning skills
Conceptual and Analytical Ability	Evaluates situations effectively
	Solves problems/makes decisions
	Demonstrates original and creative thinking
	Identifies and suggests new ideas
Learning/Theory and Practice	Learns new material quickly
	Accesses and applies specialized knowledge
	Applies classroom learning to work situations
Professional Qualities	Assumes responsibility/accountable for actions
	Exhibits self-confidence
	Possesses honesty/integrity/personal ethics
	Shows initiative/is self-motivated
	Demonstrates a positive attitude toward change
Teamwork	Works effectively with others
	Understands/contributes to the organization's goals
	Demonstrates flexibility/adaptability
	Functions well on multidisciplinary team
Leadership	Gives direction, guidance and training
	Motivates others to succeed
	Manages conflict effectively
Technology	Uses technology, tools, and information
	Understands complex systems and their interrelationships
	Understands the technology of the discipline
Design & Experimental Skills	Displays ability to design a component, system or process
	Demonstrates ability to design and conduct experiments
	Analyzes and interprets data efficiently
Work Culture	Understands/works within the culture of the group
	Respects diversity
	Recognizes political/social implications of actions
Organization Planning	Manages projects and/or other resources effectively
	Sets goals and prioritizes
	Manages several tasks at once
	Allocates time to meet deadlines
Evaluation of Work Habits	Professional attitude toward work assigned
	Quality of work produced
	Volume of work produced
	Attendance
	Punctuality

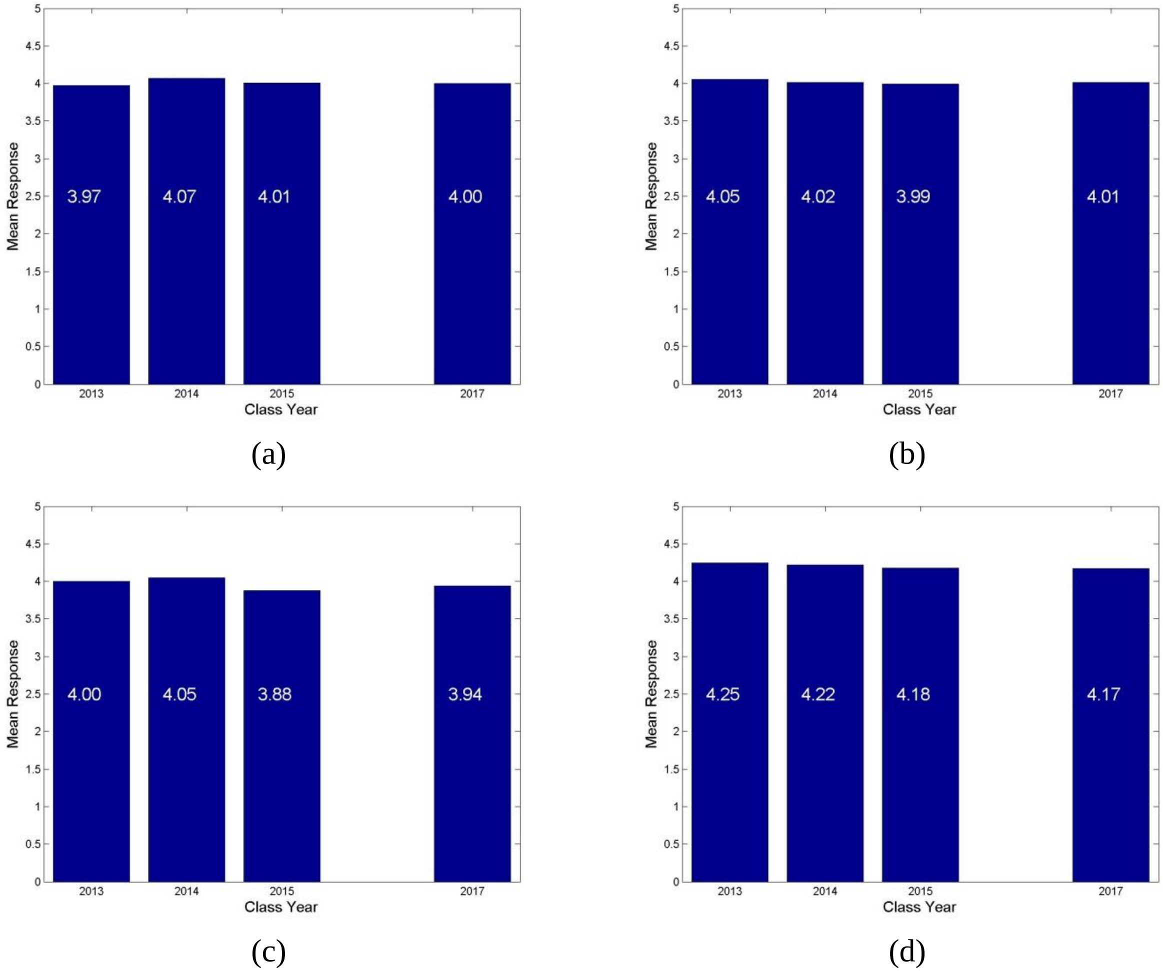

FIGURE 1: Comparison of Responses for Communication Questions (a) Speaks with Clarity and Confidence, (b) Writes Clearly and Concisely, (c) Makes Effective Presentations, and (d) Exhibits Good Listening and Questioning Skills

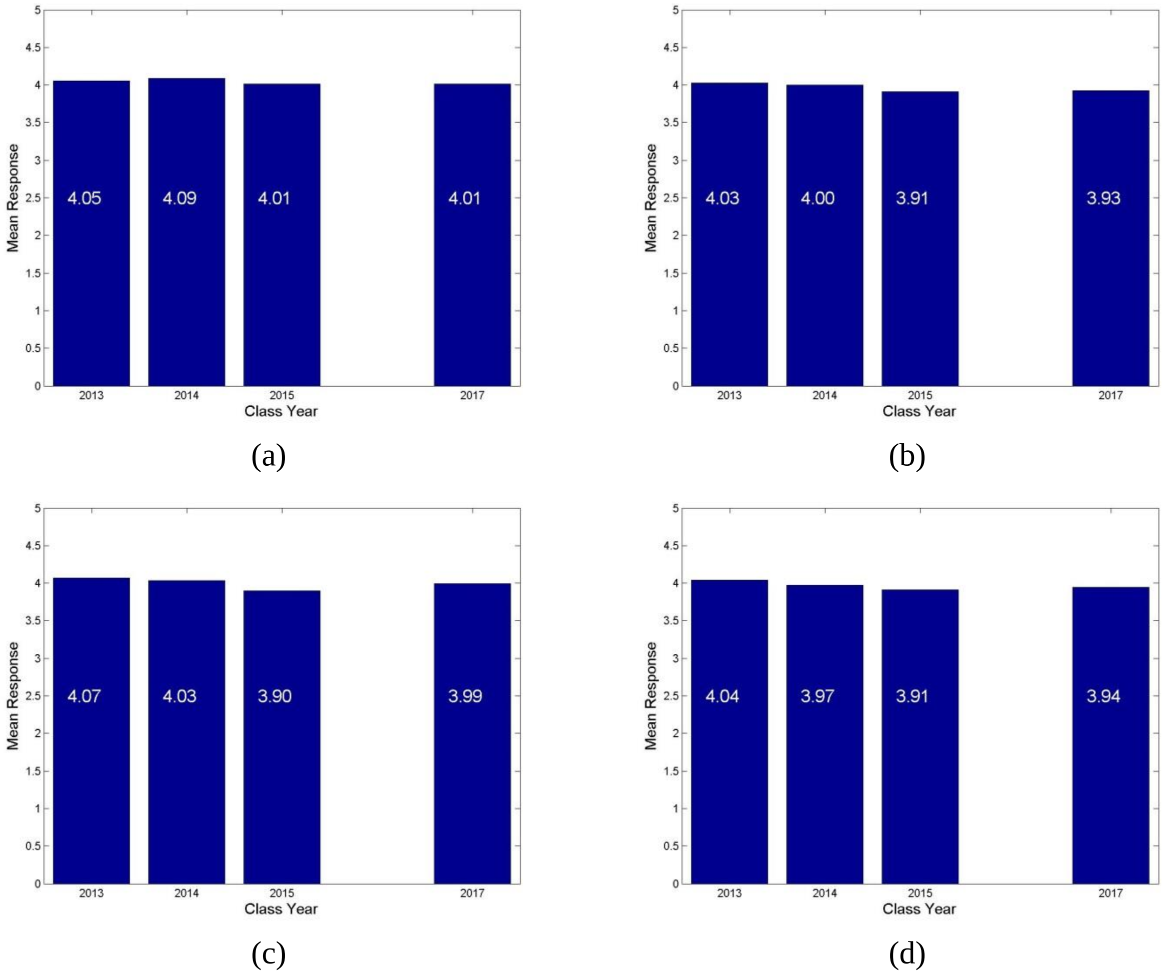

FIGURE 2: Comparison of Responses for Conceptual and Analytical Ability Questions (a) Evaluations Situations Effectively, (b) Solves Problems/Makes Decisions, (c) Demonstrates Original and Creative Thinking, and (d) Identifies and Suggests New Ideas

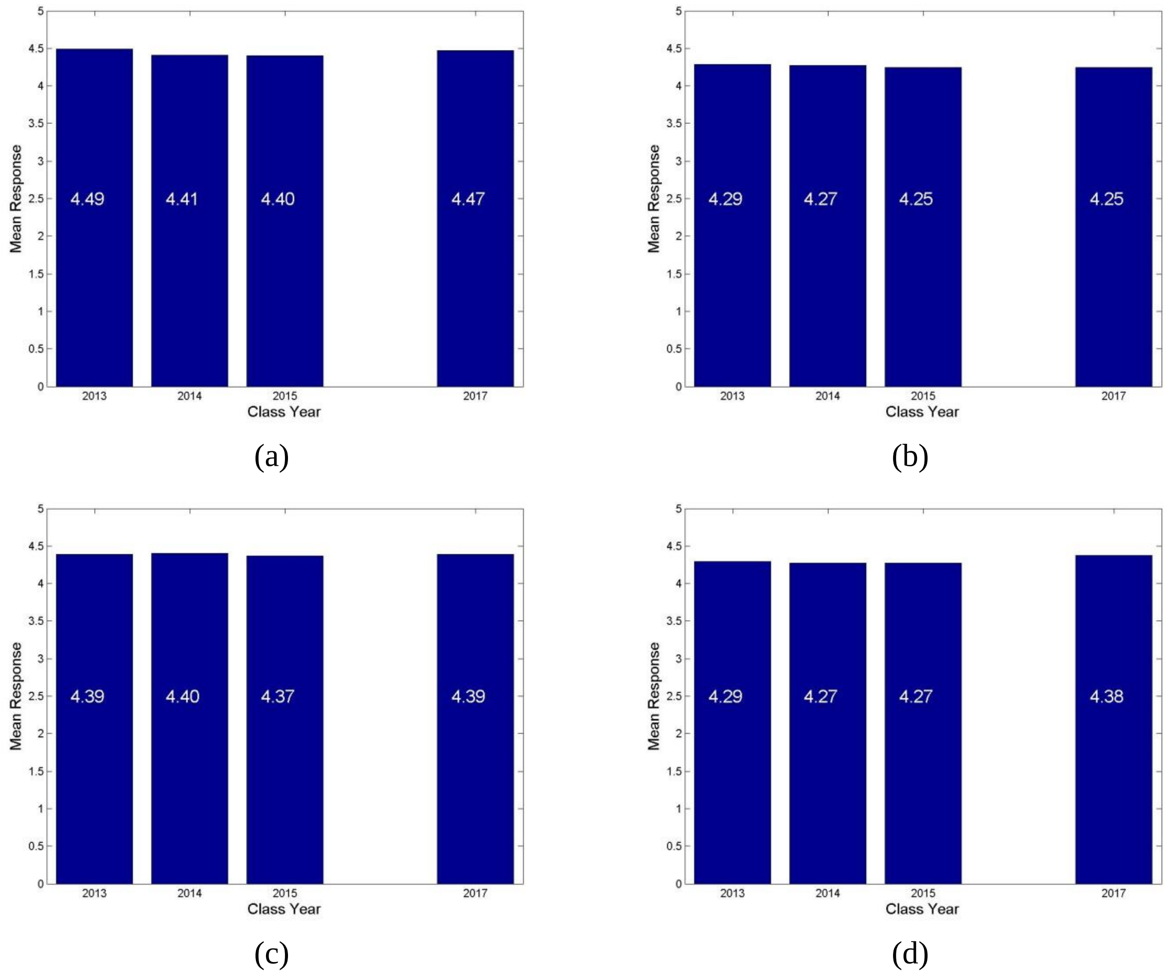

FIGURE 3: Comparison of Responses for Teamwork Questions (a) Works Effectively with Others, (b) Understands/Contributes to Organization's Goals, (c) Demonstrates Flexibility/Adaptability, and (d) Functions Well on Multidisciplinary Teams

As can be seen from the results above, there was very little difference between the responses for the four cohorts. A Mann-Whitney U test was performed to determine if any of the differences were statistically significant. Of the 123 possible comparisons (41 questions and comparing each cohort to the 2017 cohort), only 3 comparisons resulted in statistically significant results. These are summarized below.

TABLE 4: Statistically Significant Differences Between Cohorts

Question	Cohort	Difference (2017-201X)	p-value
Accesses and applies specialized knowledge	2014	-0.12	0.038
Applies classroom learning to work situations	2014	-0.17	0.008
Attendance	2015	-0.07	0.041

Given the lack of significant results arising from the numeric survey responses, several of the qualitative survey responses were analyzed to determine whether any differences can be identified. Specifically, two employer response questions were analyzed:

- List student's specific strengths
- List areas of concern regarding student's performance

These responses were analyzed by reviewing the responses and coding them based on the coop employer assessment instrument categories identified in Table 3. It was possible that each response could be assigned to multiple categories, depending on the nature of the response. Two of the authors independently coded the responses, after which the results were compared and a single set of codes were agreed upon for each response. The results are summarized in Table 5.

TABLE 5: Percentage of Responses Coded

	Strengths				**Weaknesses**			
Category	**2013**	**2014**	**2015**	**2017**	**2013**	**2014**	**2015**	**2017**
A	11.08	23.64	18.80	18.62	12.82	12.82	14.56	13.10
B	11.36	8.70	7.83	**12.41**	0.00	0.00	1.89	1.38
C	26.99	25.27	24.80	26.21	0.00	0.00	1.35	2.07
D	21.59	25.00	23.76	**30.34**	8.55	8.55	10.78	**13.79**
E	14.49	16.58	15.14	**18.62**	0.85	0.85	1.62	2.76
F	1.70	0.00	0.52	0.00	0.00	0.00	0.27	0.69
G	12.22	4.62	5.48	9.66	0.00	0.00	1.08	0.00
H	0.00	0.54	0.26	0.69	0.00	0.00	0.00	0.00
I	0.85	0.27	0.52	0.69	0.57	0.57	0.27	0.00
J	9.38	8.97	13.58	11.72	1.99	1.99	2.70	0.69
K	19.32	27.72	45.43	**50.34**	4.27	4.27	8.36	**11.03**

As can be seen from the highlighted values, the class of 2017 cohort saw an increase in the number of times employers mentioned strengths related to conceptual and analytical ability (B), professional qualities (D), teamwork (E), and work habits (K). This is a very positive result, as problem solving and teamwork are two of the items focused on during the first-year engineering courses and are attributes of categories B and E, respectively.

It is also interesting to note that while categories D and K saw an increase in the number of times mentioned as strengths, they also increased in the frequency mentioned as weaknesses. The most often mentioned weakness attributed to category D is a lack of confidence. This is to be expected with sophomore level students on their first coop rotation. The most often mentioned weaknesses related to category K were a poor attitude towards their assigned work and issues related to punctuality. Again, these are not all that surprising for students so early in their academic and professional careers. However, because of these increases, more attention may need to be given to these issues in the first-year courses to better prepare students for their first coop rotation.

Conclusion

At the University of Cincinnati, three new courses were introduced during the 2012-2013 academic year, coinciding with the switch from quarters to semesters. These courses, entitled Engineering Foundations and Engineering Models I and II, focus on developing problem solving, communication, and teamwork skills and provide a venue to tying the material learned in the variety of math and science courses taken during the first year to engineering. Since the implementation of the courses, there has been an increase in the retention rates from the first to second years. In addition, while the numeric ratings of the coop employers do not show any differences between prior classes and the first class to take the first-year engineering courses, the qualitative responses of the employers regarding the students' strengths and weaknesses show an increase in the problem solving and teamwork abilities of the most recent class. These results are promising and show that the introduction of these courses has had a positive impact on the students.

In the future, data from the subsequent cohorts of students will be added to the analysis of the coop data. With additional data, more meaningful results will be able to be gathered from the numeric survey responses. This will also allow for exploration of how future curricular modifications affect student performance. Additionally, each cohort will be tracked throughout their full set of coop rotations to see how they compare to classes prior to the introduction of the first-year courses.

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