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The Role of Undergraduate Research in an Undergraduate Engineering Curriculum

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Abstract

It is clear, that in addition to mastering discipline-specific content, the engineers of tomorrow also need to learn how to formulate questions, conduct experiments, analyze data, function on a research team, and communicate results. While some of these skills can be learned in a traditional classroom, many can be acquired by participating in undergraduate research. This significantly differs from traditional capstone design classes in that they are participating in fundamental research questions under the guidance of a faculty research mentor. This type of experience helps students better understand the nature of the discipline and what contributing to engineering research is actually like. At the University of Florida, we have developed a multi-level pathway to help students gain these experiences. The first is an introductory level course for entry level students that increases awareness of the possibilities of undergraduate research. The second are courses that integrate faculty research into the classroom. In these courses, students are trained to collect data that moves the faculty's own research program forward. The culminating experience is a mentored, one-on-one research experience in a faculty lab. At this level students enroll in course numbers that earn them recognition for their research efforts on their transcript. This pathway provides students at each level of their curriculum with opportunities to gain the types of desired skills that this participation insures. Evaluation data on each of these levels will be presented.

Keywords: Curriculum, Undergraduate research.

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Introduction

Undergraduate research (UR) has been identified as a high impact educational practice that has multiple professional and personal benefits [1], [2]. It allows students to establish a relationship with mentors and peers. Furthermore, undergraduate research gives students the opportunity to explore a specific field in depth, resulting in a more focused career path by helping them clarify, refine, and reinforce their career interests [3]. It can lead to an increased interest in pursuing a STEM career and can have a positive impact on retention [4], [5], [6]. UR can increase a student's self-confidence, independence of work and thought, and a sense of accomplishment [4], [7], [8], [9]. Access to professional networks and new sources of information allow students to become a part of the scientific community [10]. It can help students both prepare for and commit to pursuing graduate school [3], [6], [11]. Undergraduate research is also credited with providing skills that employers value such as the ability to make decisions and solve problems, communicate, and find and process information [12].

The Engineering Accreditation Commission criteria for accrediting engineering programs (ABET) include the requirements that students not only learn disciplinary content, but also learn how to formulate questions, conduct experiments, analyze data, function on a research team, and communicate results [13]. ABET accredited institutions are required to provide students with opportunities to earn these important skills. While some of these skills can be learned in a classroom, many can be acquired by participating in undergraduate research. Including an undergraduate research component in the engineering curriculum provides institutions with the ability to meet these goals. The ABET accredited University Of Florida Herbert Wertheim College Of Engineering is the second largest college at UF and one of the top three research units at UF. With nine departments, 15 degree programs, and more than 20 centers and institutes, it offers exceptional research opportunities to the 6,000 undergraduate students enrolled each year.

In 2010, UF established a campus-wide Center for Undergraduate Research (CUR) to develop, implement, and evaluate the quality of undergraduate research opportunities at UF for freshmen through senior level undergraduates. Given the size and scope of the engineering program at UF, and the connection between UR and the desired skills set of engineering graduates, CUR works closely with the College.

To provide engineering students with opportunities for undergraduate research, CUR has developed a multi-level pathway to help them learn about and become involved in UR. The first opportunity is an introductory level course for beginning students that increases overall awareness of the various possibilities of undergraduate research. The second platform is a suite of courses that integrate faculty research into the classroom. Thirdly, we offer a traditional mentored UR experience for undergraduate students who are competitively selected to work one-on-one with a faculty for an academic year.

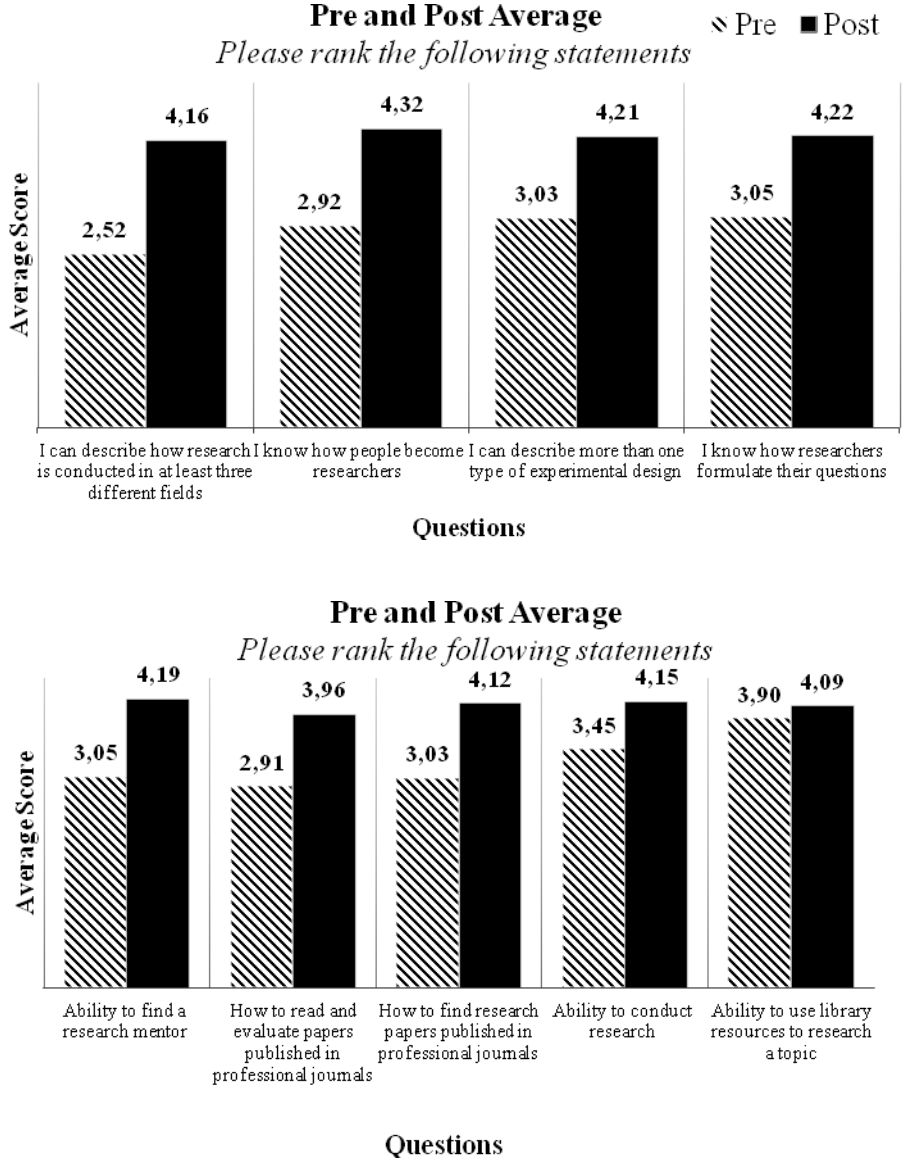
UF also offers a mechanism for a much larger group of engineering students to earn credit on their transcript for their UR efforts.

As assessing the impact of UR is an important component of UR programs [14], data from pre-post surveys evaluating students experiences are collected. We believe that these opportunities serve as an effective model that can be adapted for use across institutions that would like to provide this high impact activity to their engineering students.

Introductory Seminars

Research indicates that involving students in research early in their academic careers has many positive results, including increased intellectual gains [2]. To facilitate this, UF CUR developed a new freshman level course in 2014 called Research@UF. This is an interdisciplinary course designed to introduce students from all majors to the breadth of research being conducted at UF. Many freshmen are undecided in their majors or will switch majors in the first two years, and this survey course provides them with a greater understanding of the possible avenues they might pursue. Last year 73 students participated in this one-credit course, including 21% engineers. The course included two components. The first session of each week was a panel made up of three faculty members from diverse fields. Unlike traditional research presentations, these faculty panelists were asked to address three questions: 1) What does their research involve on a day-today basis? 2) How did they arrive at the questions they research? and 3) How did they become a researcher? This is a much more personal approach and is designed to help students understand the process of research and how people decide to pursue research careers. The second session each week was devoted to teaching basic skills, such as conducting literature searches, responsible conduct of research, qualitative and quantitative data analysis, and reading research papers. A pre and post-test was given to the students to determine the degree to which the class met the course objectives. Students were asked to rank a number of statements as shown in Figure 1 on a scale of 1-5, with 1 being strongly disagree and 5 strongly agree. Those on the top in Figure 1 assessed the students' general understanding of the research process while the questions on the bottom assessed the development of specific research skills.

Figure 1. *Pre and Post Survey Results for the Introductory Seminar*



The highest percentage increase between the two surveys (65%), was regarding the students' knowledge of research in three different fields, demonstrating that students had acquired an understanding of the various methods and approaches used in different research areas. In addition, there was a 35% increase for a student's ability to read, evaluate, and find papers published in professional journals —an essential skill at the graduate level. Furthermore, after taking this research course, students were better able to identify potential mentors with a 37% increase, and were more confident in their ability to perform research (a 20% increase). There was a substantial increase in the student's general understanding of the research process and their ability to execute this process. This course provided students with the skills they needed to find a research position.

Course-based Undergraduate Research Experience (CURE)

The second level of experience is that of a Course-based Undergraduate Research Experience (CURE). These have developed due to the fact that at a large university such as UF (undergraduate population of 32,000, including 6,000 in engineering) it is very difficult for each student to have a mentored one-on-one research experience [15]. CURE courses are designed to benefit both the students and faculty. Faculty develops a course that integrates their personal research into the classroom. Students enroll in the class, learn about the process of research in their field, and collect, analyze or otherwise assist the faculty in their own research. At the end of the course, the students have had an authentic research experience, and the faculty has data that they can use in proposal or publications. This past fall CUR worked with Dr. Eakta Jain in Computer and Information Science and Engineering to support her efforts to develop a CURE course titled *Human Centered Computer Graphics.* This was designed for upper level undergraduates but beginning graduate students were also allowed to enroll. The course was designed to demonstrate how data collected from humans drives research in computer graphics. Students were expected to collect perceptual data, propose algorithms using perceptual data to generate visual media and learn how to implement a final project and present it to a broad audience. Although the course was offered to both undergraduate and graduate students, unexpectedly, the undergraduates who initially enrolled dropped the class. Dr. David Lopatto at Grinnell College has developed an assessment tool for CURE courses, and provides feedback regarding learning gains made by participating students over the time of the course, and also compares them to his national database. He conducted an assessment of this course (Figures 2 and 3). It is clear that for these early graduate students, the course resulted in gains in both learning and content areas that exceeded national averages. When offered again, a modified approach to recruit and retain undergraduates will be developed. CUR will work with other engineering faculty who would like to integrate their research into the classroom using this model.

Figure 2. *Engineering CURE Course Element Gains* (CURE Analysis provided by Dr. David Lopatto, Grinnell College)

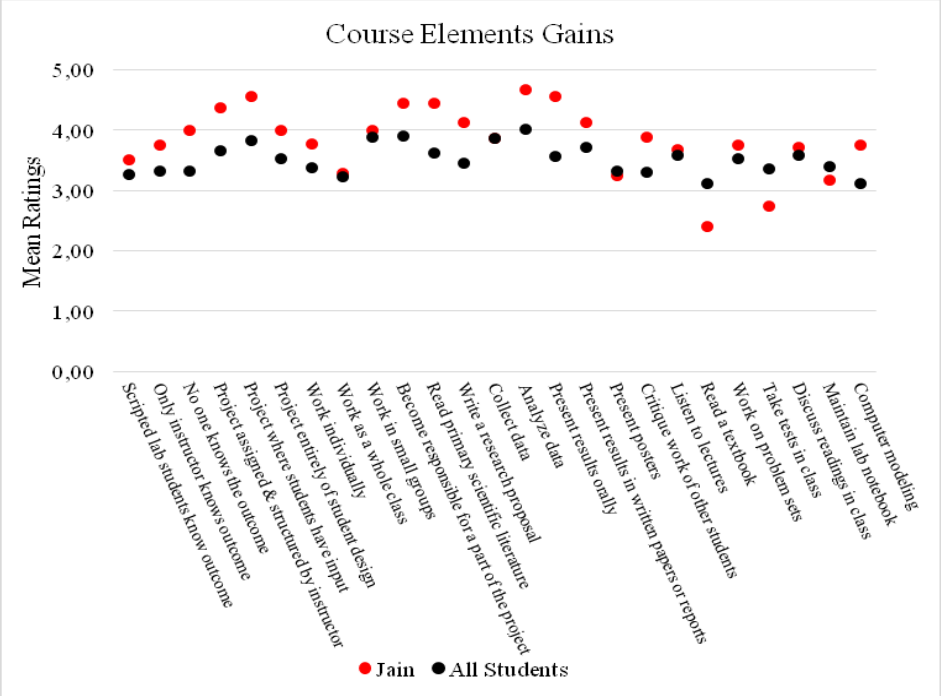
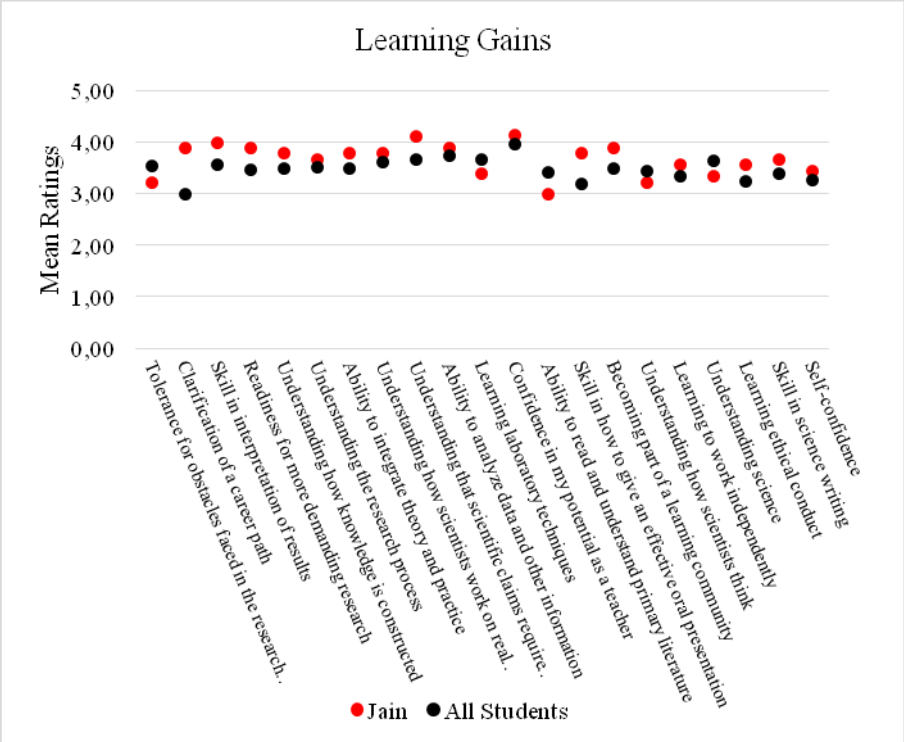


Figure 3. *Engineering CURE Course Learning Gains* (CURE Analysis provided by Dr. David Lopatto, Grinnell College)

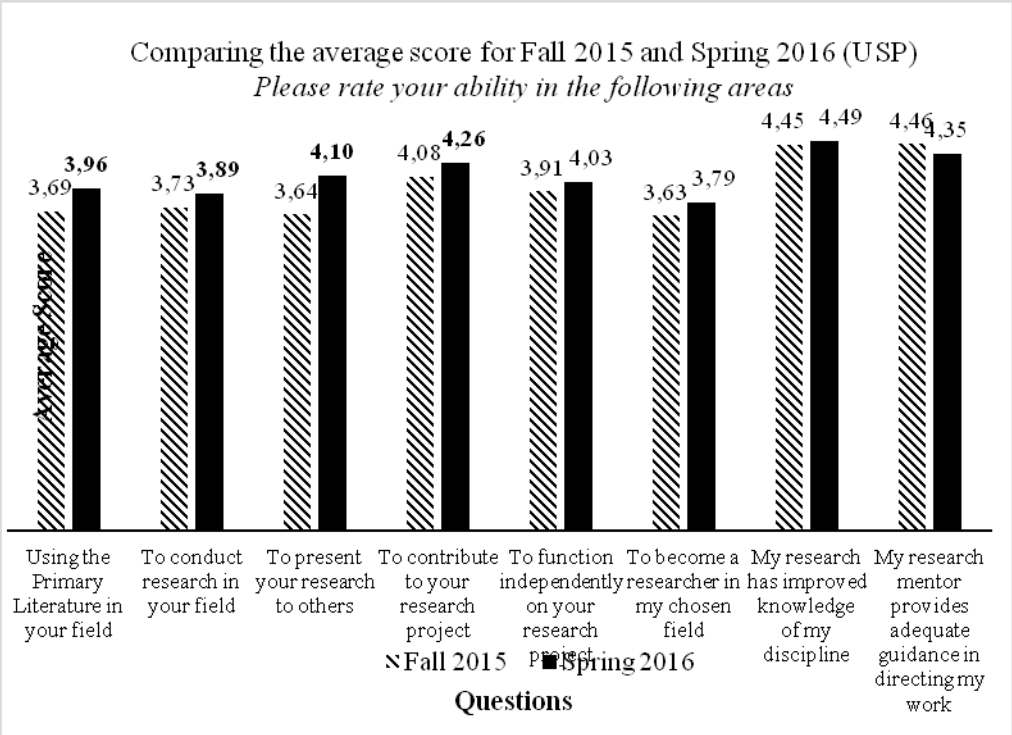


University Scholars Program

The USP Scholarship program offers a mentored research experience that lasts one year and has 200 participants that are selected annually from all disciplines through a competitive process. Last year participants were overwhelmingly seniors (87%). Last year 38 engineering students from 10 departments participated in this program. Students are expected to conduct the research project with their faculty mentor and are often also guided by graduate students and Post Docs. They are required to present a research poster at the Annual UF Undergraduate Research Symposium and to meet a publication requirement. This year, 15 of the engineering researchers (40%) are named as co-authors on a peer reviewed journal submission. This is evidence of the quality of their contribution as well as the support of the faulty who recognize their contributions. Having publications on the undergraduate level enhance the students resumes as they move into the work force or graduate school.

To assess the impact of the program, students are required to complete a pre and post survey, as are faculty mentors. Survey results were analyzed using a paired sample t-test to see if there were any statistically significant changes in any of the survey questions over the research experience.

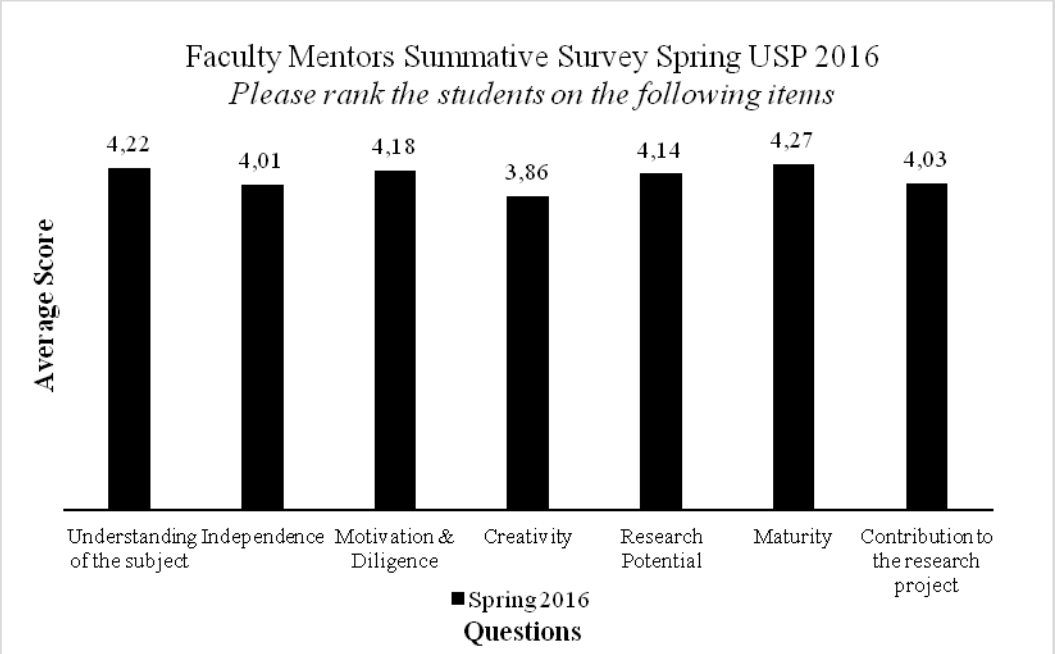
Figure 4. *Fall 2015-Spring 2016 USP Survey Results. Pre-Post Survey Response to "Please Rate your Ability in the Following Areas". Bolded Quantities Indicate Significance of p<.05. (Ratings: 1=Very Low, 2=Low, 3=Average, 4=High, 5=Very High)*



As shown in Figure 4, there was a significant increase in the first four questions; a student's ability in *Using the Primary Literature* ($p<.001$), to *Conduct Research* in his/her field ($p=.01$), to *Contribute to your Research Project* ($p=.003$) and *Presenting your Research to Others* ($p<.001$) signifying the benefit of the multiple presentation opportunities students are offered throughout the year.

In the faculty USP Spring 2016 surveys, most responses were above 4 on a five point scale as shown in Figure 5. This indicates a high degree of performance of the USP Scholars as rated by their mentors.

Figure 5. *Summative Evaluation of USP Students by Faculty Mentor following the Completion of the Program. (Ratings: 1=Very Low, 2=Low, 3=Average, 4=High, 5=Very High)*



Undergraduate Research Courses

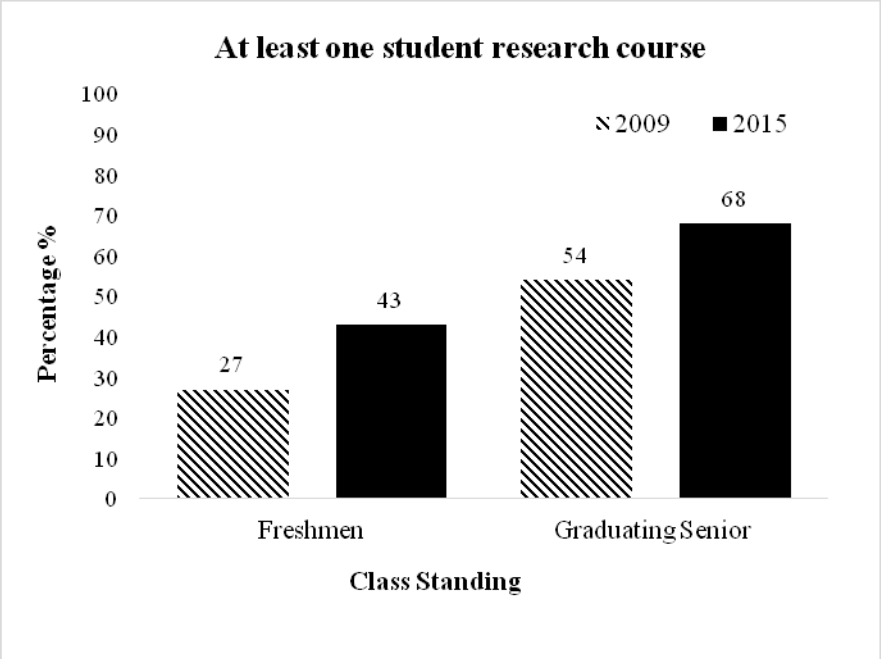
The USP program only includes 38 engineering students, and as mentioned, they are primarily seniors. We encourage all students to pursue a mentored research experience however and have developed a mechanism for them to do so as part of their engineering curriculum. When CUR started, there was no standardized mechanism for students to get recognition for their undergraduate research efforts on their transcript. CUR worked with each college to develop a course number specifically titled "undergraduate research". The College of Engineering now has a variable credit (0-3) course number that all students conducting research in the college register for. Two issues that were addressed were cost and excess credit. To avoid students accumulating excess credits and having to pay for them, there is a zero credit option. Students can opt to receive recognition on their transcript at no cost and

not add excess credits. Enrollment in this course for the 2014-2015 academic year was 344 students. This has grown this year (2015-2016) to 436 students. This now allows a formal recognition of their undergraduate research efforts.

Assessing Campus Impact

The University of Florida participates in the Student Experience in the Research University (SERU) survey every two years to allow continued monitoring of the UF student experience [16]. The survey was developed by the University of California at Berkeley Center for Studies in Higher Education. Since 2004 all of the universities in the UC System have administered the SERU survey. In 2015, 8 public Association of American Universities institutions administered it: UF, Texas A&M, University of Minnesota, University of Michigan, University of Washington, University of Virginia, University of North Carolina at Chapel Hill, and the University of Pittsburgh. The 2015 survey was conducted online and at UF 10,250 students (a 32.5% response rate) completed it. A series of questions concerning student participation in research activities are included and this allows us to monitor overall campus participation in UR, and to compare our participation to that of other SERU schools. Research course participation at UF grew from 2009 to 2015 (Figure 6). There was a 14% increase in 2015 in graduating seniors reporting a student research course with a 16% increase for freshmen.

Figure 6. *Survey of Research University (SERU) Results Reporting Participation in Research Courses at UF in 2009 and 2015 by Class Standing*



Conclusions

The establishment of a campus-wide Center to promote undergraduate research has enhanced opportunities for engineering students to learn about and participate in UR. This is an important component of an undergraduate engineering curriculum as it provides them with many skills not easily obtained in a traditional classroom setting. The introductory course provides an interactive approach with faculty, and students are able to develop a greater understanding of different research fields and of the research process. The Course-based Undergraduate Research Experience (CURE) resulted in gains in both learning and content areas for engineering students that exceeded national averages. In addition, the 2015-2016 USP Program demonstrated a significant growth in students' ability in using the primary literature, presenting his/her research to others, to conduct research in his/her field, and to contribute to his/her research project. The various additional opportunities offered by CUR including the UR symposium, research seminar series, and publication opportunities are excellent ways to integrate undergraduate research into the engineering curriculum and help students gain important professional development skills. We believe that this model of various entry points to undergraduate research in engineering can be successfully implemented in other organizations and produce significant impacts.

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