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A Comprehensive College-Centered Engineering Undergraduate Research Program

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Abstract:

Undergraduate (UG) research is an important component of today's engineering education. Research experiences allow students to explore beyond the classroom by applying concepts towards scientific discovery and the development of products and technologies that impact society. The number of UG engineering students interested in participating in research is increasing. However, UG research opportunities are often limited to students finding a project, laboratory, and mentor on their own. Therefore, only a handful of students typically benefit from a mentored UG research experience. In addition, students seeking UG research opportunities and projects have little, if any, knowledge on how to conduct research. A well-structured, guided UG research program could enhance the undergraduate experience of a large number of students and better prepare them for making an appropriate postgraduate choice (industrial R&D, graduate school, etc.) that would lead to career success.

In Armour College of Engineering at the Illinois Institute of Technology, we have developed and implemented a college-centered engineering Undergraduate R&D Program that teaches students the art of conducting research using a comprehensive approach. The students are introduced to research methods and concepts through a research course, and a series of competitive research project opportunities is provided. In addition, students are required to present their research findings at a college-wide research expo and submit a paper to student-reviewed campus research journal. The program aims to impact a large number of students interested in working on research and development projects in all disciplines within engineering. The program is centralized at the college level and supports student/faculty teams that compete by submitting formal proposals focused on basic research projects or the development of a technology or product. Proposals are solicited every semester, including summer, and reviewed for quality and impact with special attention to the mentoring plan. Since its inception (Spring 2013), 178 projects have been supported, with participation of engineering students in their second through fourth years. Student participants in this Armour R&D program reported acceptance of their work for presentation in national conferences, received research awards, and published in peer-reviewed journals. Surveys have been implemented to evaluate the impact of the UG research experience on graduate school acceptance rates, industrial internships, and placement opportunities upon graduation. Currently available metrics support the significance and impact of this program on student education and career success. In this paper we present and discuss a more comprehensive analysis of the results from the assessment of the program.

Introduction:

The essence of the undergraduate engineering education experience is constantly changing. The past few decades have witnessed the addition of new educational aspects to engineering curricula and programs, with main goals and objectives aiming at improving the student's ability to function in a realistic workplace. The emphasis has been placed primarily on developing curricular content to enhance and sharpen communication, teamwork, and leadership skills.

In the same vein, several engineering programs are also recognizing the importance of developing the student's ability to conduct research, and are experimenting with various ways to

integrate research exposure into the undergraduate experience. Undergraduate research has been identified as an educational practice that addresses challenges facing engineering education[1,2,3]. A number of researchers have provided data to support these claims. Undergraduate research increases the interest of participants in pursuing a STEM career[4], graduate education and additional research experiences[5]. In a survey of 41 programs these experiences were found to enhance the overall education experience[6]. Overall, engaging undergraduates in research is likely to increase interest in careers in engineering, improve retention of undergraduates in engineering fields and increase the number of people interested in advanced engineering degrees.

Despite this interest, research remains a controversial aspect of undergraduate engineering education. On one hand, the impact of a successful undergraduate research program on the developmental path of students who seek a career in Academia, industrial, or governmental Research & Development (R&D) is highly touted. On the other hand, unlike communication and teamwork, research is not universally accepted as a fundamental skill for engineering graduates. As a result, research is not prescribed across the board in engineering programs. In addition, the lack of uniformity in research experiences create challenges when providing credits that count towards the degree requirement. Thus, care must be taken when attempting to include research as a curricular, or extracurricular option. Programs need to be designed that cater not only to students who have a firm commitment to an R&D career, but also to a broader sector of the student population comprising students who are still in search of their career focus and objectives.

Undergraduate research has received strong support from the National Science Foundation (NSF) through the development and funding of many research opportunities, including Research Experiences for Undergraduates (REU), Research in Undergraduate Institutions (RUI), Historically Black Colleges and Universities Undergraduate Program (HBCU-UP), and Louis Stokes Alliance for Minority Participation (LSAMP) Program. While these programs provide serious avenues for research preparation for students seeking further education at the graduate level, there is a need, as outlined above, for broader-reaching programs. Thus, many institutions are currently experimenting with the introduction of programs that support undergraduate research activities internally.

While individual research positions in a faculty lab provide opportunities for some undergraduate students, these are often difficult for students to identify resulting in many students feeling unable to find appropriate experiences. College-focused programs can be more far reaching and allow for oversight in regards to the nature of the experience. It has been stated that it should be within the mission of universities to introduce undergraduates to research[7]. The college of engineering at University of Delaware developed an Institution-wide Undergraduate Research Program operated centrally and based on matching interested students to faculty research. They conducted a survey to measure the impact of undergraduate research on the career of over 2,000 alumni. They concluded that participants in undergraduate research rated their experience as “very important” to their career, were more likely to pursue graduate studies and generally reported higher skills than the rest of the sample. A similar survey of faculty perception reports general agreement of the faculty involved in mentoring undergraduate research with the benefits of the experience[8,9].

Within Armour College of Engineering at the Illinois Institute of Technology we have developed several programmatic offerings in regards to undergraduate research. The most recent of the efforts, and the subject of this article, is the Armour R&D program offered under the umbrella of a Distinctive Education Initiative within the college of engineering. The program supports students conducting supervised research with faculty based on a proposal developed and submitted by the student-faculty team. The emphasis placed on formation of student-professor teams is one of the important aspects of this program. A survey of research teams consisting of undergraduate students and faculty reports a high level of satisfaction by all constituents, and further reports greater levels of achievement and skill enhancement[10]. The Armour R&D program consists of two platforms: PURE (Program for Undergraduate Research in Engineering), and MIND (Mentored INnovation and Development). The program was launched with PURE, which deals with basic and fundamental research projects. MIND was added, most recently, to accommodate projects that are focused on the development of a prototype or product, or on translating a research idea into a practical application.

Student-faculty teams are required to submit a mentoring plan as part of the application process. This is considered a critical part of the review process. The development of mentoring relationships has been reported to enhance the research conducted[11,12], and undergraduates who report stronger faculty support tend to have higher probabilities of reporting plans to enter a graduate STEM program[13]. However, the mentoring relationship has become more complex due to the increasing interest in undergraduate research opportunities and the many different professional responsibilities of faculty members that may be more valued in the tenure and promotion process. To meet the demand many faculty assign their graduate students to provide the one-on-one mentoring to the undergraduate students[14,15]. However, this complex interaction requires careful planning as there ares some responsibilities that graduate students and faculty can share but others that are specifically attributed to the faculty mentoring relationship[16]. Based on this knowledge, the mentoring plan was considered a critical component of the review process.

This article is one of four contributions aimed at presenting various programs developed at the Armour College of Engineering under the umbrella of the Distinctive Education Initiative. The other activities include course-based experiential learning, development of student-based engineering portfolios and a course based approach to engineering research education (references to papers will be inserted here following blind review). The Distinctive Education Initiative offers students extra-curricular and curricular opportunities for educational enrichment. Four Engineering Themes were identified at the launch of the initiative in 2011 as having societal and scientific relevance and deserving of consideration as areas of enrichment of the educational experience of our students. The themes were selected to provide broad umbrellas that address research and education strengths that bridge the five engineering departments (Biomedical Engineering; Chemical and Biological Engineering; Civil and Architectural Engineering; Electrical and Computer Engineering; Materials, Mechanical and Aerospace Engineering) within the College. Those themes are: Energy, Health, Security, and Water. The distinctive education team includes 4 faculty co-directors, each in charge of coordinating the activities of a specific theme.

Program Overview:

The undergraduate research program was initiated in Spring 2013 and has been ongoing for seven semesters, including summers. Initially the program primarily supported basic research projects. However, in 2014 two distinct mechanisms were established, one that supported basic research and another that supported projects focused on technology or product development.

Applications are considered from student/faculty teams. Proposals are divided into 3 sections: 1) research description, 2) student background and 3) mentoring plan. The proposals are solicited every semester, including summer, and reviewed (by a faculty panel and the college dean) for quality and impact with special attention to the mentoring plan. Although the program generally places the onus of formation of these teams on the student, the college assists as needed. To help start the program, the college of engineering distinctive education faculty team offered help, in the first 2 semesters, by introducing several of the students seeking research but lacking a mentor to potential faculty mentors. On ongoing basis, the student is responsible to search for professors whose research match his/her interest, and approach them for further discussion. The program provides funding over the course of a semester for student stipend. Research costs are typically supported through other mechanisms, typically grant funding to the investigator.

Thematic Categorization:

The proposals submitted to the Armour R&D undergraduate research program are focused in one or more of the four thematic areas, Health, Energy, Security, and Water. The college R&D application and proposal must include information and details about the relevance of the research project to one or more of the specified engineering themes.

Research Course:

As detailed in a separate contribution (ASEE paper submission entitled *ENGR497: An Introduction to Research Methods Course*), the distinctive education initiative has developed and introduced a course on research methods. Students participating in the Armour R&D program were encouraged to take this course as part of the program. The course introduces students to research methods and contemporary issues related to research in a university setting with a focus on applying engineering methods to the research discovery process. The course was developed so that students from all disciplines could participate (i.e. no pre-requisites were required). Students are introduced to proposal development, scientific and technical literature reviews, measurement techniques, statistical data analysis, design of experiments, good laboratory practice, and oral and written research communication. Ethics and intellectual property topics related to research are also covered. During this course, students are involved in hands-on experimentation to practice their measurement and data analysis skills as well as test their hypotheses and/or the validity of their approach to the specific topic being investigated.

Research Expo:

Students are required to present their research findings at a college-wide research and development (R&D) exposition, held at the end of each semester with the major event at the end

of the academic year. The guidelines and style of the exposition are meant to mimic poster sessions at national engineering and science meetings. The students present to a team of judges (faculty, doctoral candidates, and other invited guests) who evaluate both the poster and the presentation on criteria of scientific and technical content and presentation skills; awards are given to the highest scoring projects.

Reporting Requirements:

At the end of the semester the students are required to submit a project report detailing the results collected during the conduct of the research. They are also highly encouraged to submit, with support and guidance of their research mentor, a journal-style manuscript to a campus-based undergraduate research journal. Those articles are peer-reviewed, and the journal provides an opportunity for students to learn the process of journal submission, practice technical writing, and be exposed to the peer review process.

Student Survey:

In 2014 we conducted a survey of all students who had participated in this program, to assess the performance and impact of the program. The assessment used was a survey with both a five-level Likert-scale and open-ended questions, and administered by email. The Likert-scale questions asked students to score the following items:

- Question 1: The quality of mentorship received.
- Question 2: The value of the experience.
- Question 3: The influence of the experience on pursuing additional undergraduate research experience and/or graduate school.
- Question 4: The influence of the experience on the likelihood of seeking a career in research and development.
- Question 5: Whether the experience has enriched their education.

Demographic Analysis:

Since its inception (Spring 2013), 217 applications have been received and 176 projects supported (81.1% funding rate). The program allows students to receive more than one semester of support. Fifty percent of the awards went to students who were new to the program and 50% to returning students. The returning students typically participated for 2 semesters, but some participated for as much as four semesters. Third year (37%) and fourth year (41%) undergraduates received the majority of the awards, but funding was also provided to first year (4%), 2nd year (8%) and 5th year (8%) undergraduates. Visiting students (4%) and transfer (4% students) were also supported. The college consists of 1,452 students and 86 faculty members. Overall, 49 faculty members (57%) have submitted proposals to the R&D program.

Projects were supported across a broad range of engineering topics as shown in Table 1. Undergraduates representing all engineering disciplines within the engineering college have been supported: 28% mechanical, materials and aerospace engineering, 24% biomedical engineering, 24% civil and architectural engineering, 12% chemical and biological engineering, and 12% electrical and computer engineering. The research course was not required to qualify for funding, but 18% of students opted to take the course in addition to performing research.

Table 1: Sample Projects by Theme	
Title	*Theme*
Sensor-Based Structural Health Monitoring in Tall Buildings	Security
Modeling the Energy Impacts of Filter Fouling in Existing and Old Homes	Energy
Introduction to Double-Ring Infiltrometer: Instrumentation Methodology for Measuring Soil Infiltration Rates	Water
Finding Improved Protocols for Using Deep-Brain Stimulation for Treating Epileptic Seizures	Health
Innovative Control Effectors for Maneuvering of Air Vehicles	Security
Hydrogen Evolution Reaction Catalyst for Solid-State Alkaline Water Electrolysis	Energy
Open-Source Water Quality Monitoring Sensors	Water
Development of Engineering Devices for Affordable Nutrition	Health

Dissemination of Research Results:

Students presented their research results through several pathways. All students were required to participate, and present their latest work at the Armour R&D expo. A group photo is provided from Fall 2014 in Figure 1.

Figure 1: A group of participants in the Fall 2014 Armour R&D Exposition

Additionally, the students were required to submit a final report in each semester. Several students submitted their research in the form of a journal-style publication. A selection of these was accepted for publication in a campus-based undergraduate research journal.

In addition to the campus presentations and journal, some students were able to present at national meetings and published articles in peer-reviewed engineering and science journals. A number of the students received national recognition for the quality and contributions of their research (Table 2).

Table 2: Sample Honors Received by Undergraduate in the College Research Program
Paper defined as required reading material by the National Fire Protection Association
American Society of Civil Engineers Practice Periodical of Structural Design and Construction top ten downloaded articles of 2014
Biomedical Engineering Society Undergraduate Design and Research Award
Travel award for the 2014 Tissue Engineering and Regenerative Medicine International Society Annual Conference and Exposition

Survey Data:

Starting in the fall of 2014 we implemented a survey to evaluate the impact of the program on the participants. Over the two semesters in which the survey was implemented, 55 students were supported and 27 survey responses were received, giving a 49% response rate.

On average the participants provide positive feedback with means greater than 4 for on all areas surveyed (Table 3). When examining individual questions the distribution of responses could be seen in greater detail. In regards to mentorship, 92% of students rated the experience as "excellent" or "good" (Figure 2a). While low, 8% of students did identify the mentoring experience as "lacking" or "poor". The overall value of the experience was identified as "excellent" by 63% of students and "good" by 33% of students (Figure 2b).

Table 3: Likert Survey Results	
Question	**Mean (range)**
The quality of mentorship received.	4.3 (1-5)
The value of the experience.	4.6 (2-5)
The influence of the experience on pursuing additional undergraduate research experience and/or graduate school.	4.6 (2-5)
The influence of the experience on the likelihood of seeking a career in research and development.	4.3 (2-5)
Whether the experience has enriched their education.	4.6 (1-5)

Undergraduate research experiences are often expected to increase the likelihood of an undergraduate pursuing additional research experiences, attending graduate school or seeking a career in research. When asked about their interest in additional research, over 80% of students agreed that they may consider additional research or attend graduate school (Figure 3A). The numbers were slightly lower for careers in R&D. While 77% agreed that the experience had an impact, 18% remained undecided (Figure 3B). Undergraduate experiences are often designed to also enhance the educational experience. Over 92% of students participants agreed that the experience enriched their education (Figure 3C). Four percent of students disagreed.

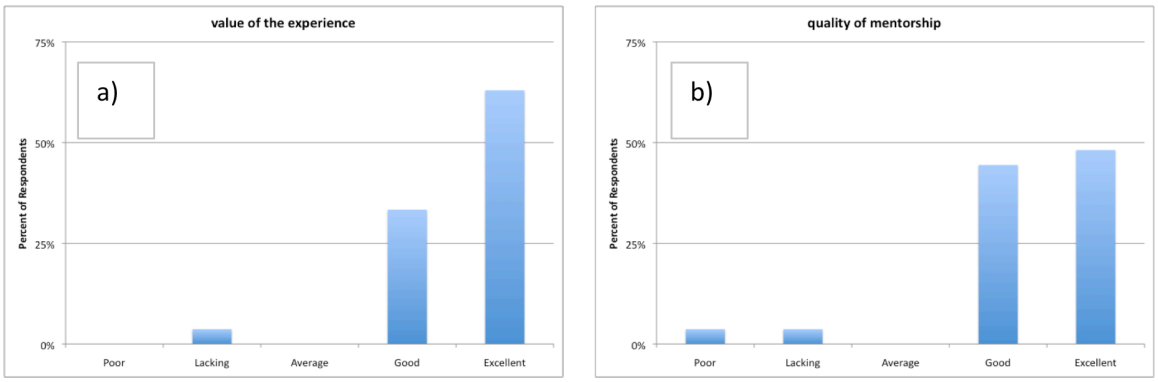

Figure 2: Distribution of student responses for survey questions on (a) mentorship and (a) the overall value of the experience.

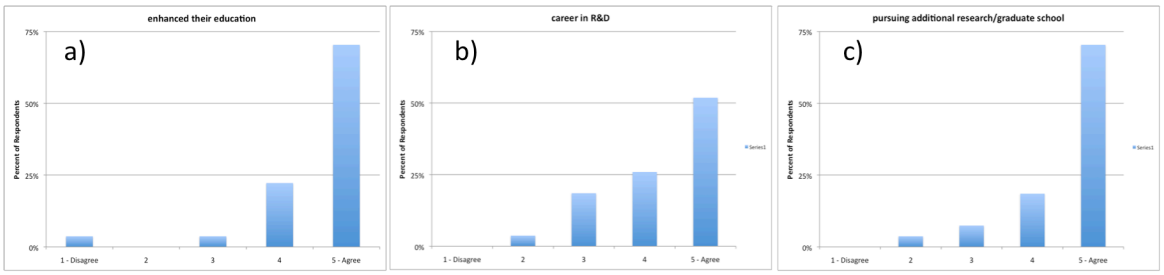

Figure 3: Distribution of student responses for survey questions on the impact of the research experience on (a) interest in pursuing additional undergraduate research experience and/or graduate school, (b) seeking a career in research and development and (c) enriching their education.

Discussion:

In this article, we have presented details and results about an undergraduate R&D program centrally administered at the College of Engineering level, and specifically under the umbrella of a Distinctive Education Initiative. Limited survey results have been collected but, when taken alongside other input from faculty and students involved in the program, provide useful insight into the assessment of success of the program.

Conduct of a broadly reaching undergraduate research program is quite challenging. If it is offered solely at the individual level through a formal research course, or direct recruitment by faculty it ends up being narrow in its focus, and usually only benefits students with clearly developed career goals. On the other hand, organizing programs at the department or college level requires careful planning and heavy involvement. Some institutions, including ours in the past, have attempted to run these programs strictly in matchmaking mode. In this mode, faculty members post their recruiting materials and interested students are offered a chance to compete for the positions. The results are not much different from the individual mode described above. We have now developed a centralized program that calls for proposals from student-faculty teams, reviews applications, and grants participation to the best developed proposals. Review criteria include technical merit, student background, and the mentoring plan developed jointly by the faculty and the student. This program distinguishes itself through two important aspects: a) A stipend is offered to the student from the centralized program, and b) The program goal is

twofold. We aim to both help students discover their level of interest in research, and to provide ample opportunity for those students to achieve a high level of accomplishment in research before completing their undergraduate degree. While both aspects create distinction for the program, they also pose challenges for the long term sustainability of the program. These are discussed herein.

Analysis of demographics, survey results, and other inputs have provided several observations about the program. In regard to demographics, the program has a near 50:50 ratio of "new" to "returning" students selected for conduct of the research. This is often a major criticism in the literature of other programs, as they do not place enough emphasis on recruiting students who are new to research.[6] Our program, as it intends, clearly manages to achieve good balance between the two demographic groups. Success in this regard results from placing the proper emphasis on giving a level of preference to those applicants who have not been exposed to research, while also encouraging the return of top performing students in the program. When scoring applications for selection during the review "new" and "continuing" research students are identified. The final decision ensures that all objectives are satisfied.

As such, we find that the involvement of returning students enhances the value of the program, as those play an important role. They not only serve as role models for new incoming students, but they also possess a higher potential to achieve national recognition and/or publish their results. This helps fulfill the goals of the program and brings higher visibility to our graduating students and our program.

On the flip side, however, the demographic analysis shows that a large number of participants in the program are third, and fourth-year undergraduates. This probably results from the faculty-student interaction dynamics. On one hand, the high expectation of faculty leads them in the direction of teaming up with students in upper standing preferentially. On the other, students feel the need to establish comfort with their studies and their connection with the faculty before attempting to enroll in the undergraduate research program. In general, NSF REU programs, and similar programs form other agencies, place an emphasis on involving juniors as they are more likely to benefit from these programs. Our program aims to involve students at all levels of their studies. Our analysis shows that we have funded first year students and transfer students. We are actively working towards increasing participation of freshmen and sophomores. We firmly believe that in the long run, early exposure to research will yield the highest impact and level of success. We will experiment with a few ideas aimed at attracting those in our announcement for the summer program. It should be noted that the program is not limited to senior and junior students, but that the imbalance results from a natural process of self-selection by the students as described above.

Another important discussion point is the program funding mechanism. In the initial years, we have been running the program relying on a combination of internal institutional funds and private philanthropic support of alumni origin. The central provision of a student stipend directly from the program, rather than from the faculty mentor, removes any concerns about risks on the part of the latter. It is one of the main features of our program that has allowed the participation of students who are new to research, and who are yet unsure of their career objectives. Long-term sustainability of the program requires that we have continued ability to

provide stipend to more and more participants without having to rely on the limited currently available funds. In order to achieve this higher level of sustainability, we are progressing in two directions. In one direction, we are developing a campaign to target a new avenue for funding supply through Corporate Sponsorships. We believe that the prime goal of the program to develop the research skills of graduating students is of high interest to prospective employers, and that detailed knowledge about the achievements of our students would attract them to the sponsorship program. We are working with the Career Management Center in preparing material to be shared with prospective corporate sponsors. We are also planning to invite alumni and friends who are in engineering practice in (the city) to act as judges of our upcoming expanded research symposium. One of our goals of the corporate sponsorship program is to also create an early relationship between prospective employers and our graduating students in the hope of supporting even better placement results. We are also fully engaged in showcasing our student accomplishments to our alumni network, hoping to generate interest and engagement towards increasing the private individual support of this program.

It is well-established that mentoring relationships are critical to research experiences for undergraduates[13,16,17]. Students with stronger mentoring relationships report an increased likelihood of pursuing post graduate STEM degrees[13]. The mentoring plan was highly emphasized in our review of applications as this relationship was considered of critical importance. If the plan was not well-developed the proposal was often returned to the student/faculty pair for further refinement. The plan was evaluated on the frequency of the interactions, nature of the interactions (e.g. group vs individual) and whether the interactions were tailored to specific student needs. Overall, 92% of students rated the experience as "excellent" or "good", but 8% of students did identify the mentoring experience as "lacking" or "poor". The students were not provided with information on what a good mentoring relationship means. Instead they were expected to reflect on their own expectations. In regards to the negative experience one student commented:

"*My mentor seemed to push off all mentorship work to her PhD students. I felt guilty asking questions because she would hand all the questions over to her extremely busy students. The students took a lot of time out of their day to meet and discuss with me and I thank them for that. However, I don't think that's how the mentorship program should have worked*."

This is a very interesting comment, as recent studies suggest that it is increasingly difficult for faculty members to directly mentor undergraduates due to their many other professional responsibilities[14,15]. In fact, many faculty members assign graduate students to provide the one-on-one mentoring to the undergraduate students[14,15,18,19]. This allows for a greater number of undergraduates to be mentored and provides important mentoring experience to the graduate students. Overall, the student comment points to the importance of gaining a better understanding of these relationships and setting expectations for all people involved in the interactions.

We are also pursuing a transition process for the students from the Armour R&D program to a longer term relationship with their faculty mentors. We are achieving this by gradually imposing limits on the involvement of returning students. Although not fully developed yet, the plan is to limit each student to a maximum of one semester and one summer. However,

supporting a maximum of two semesters and one summer in cases of demonstrated highest performance. Once this is in place, the program will be able to provide a higher focus on recruiting "new" students, as well as freshmen and sophomores. It will also encourage the transition of the student-faculty relationship to either project-funded research in the faculty mentor's laboratory, or the enrollment in a research course for credit. Students who have completed multiple semesters in our program are perfectly suited for either of these endeavors. We have not yet established a mechanism for tracking the percentage of student-faculty teams that successfully transition to a long-term relation, but will start including this in future surveys.

Faculty engagement in this program has been exemplary and has greatly benefited our students, but participation has been limited to only a fraction of the college faculty. We have been pleased to observe that new faculty participants have emerged every time the program has been offered, and that many faculty members in the college have been inquiring about the program. However, we still aim to increase and diversify faculty participation. We plan to develop and conduct a faculty survey specifically addressing undergraduate research.

As discussed earlier, and as attested to by Table 3, several of our students have received honors and awards as a result of their involvement in this program. This is one of the measures of success of the program and should be further encouraged and enhanced. For example, it is highly encouraged and expected that the participants will submit their work to conferences and journals for presentation and/or publication. Costs for attending these conferences are supported by individual faculty, departments or the college. As stated before, one of the dual perspectives of the program is to heighten the level of accomplishment of academic/research career oriented students.

Overall, the survey data collected so far have been somewhat informative, but need to be better designed to provide more quantitative and perceptive assessment of the program. We recognize the need to implement a more sophisticated survey system. Some of the additional information we would seek is a better understanding of: Why some students identify a negative experience? What are the factors that lead students to classify a faculty as a bad mentor? Why did some students decide that they were not likely to pursue a research career? Why did some feel that the experience did not impact their education? We believe that a deeper level of probing for answers from the students could help inform us on how to continue to improve and design the research experience such that maximum positive impact is achieved for a larger number of students.

Finally, among our future plans for improvement are our ongoing plans to offer additional specialized courses and to better integrate them into the student's educational program. This semester, two new courses on product development are being tested with a small population of students and might be expanded in future semesters. We are also interested in obtaining feedback about our program from a larger sector of the student population. We have started an effort to survey the entire engineering student population as part of a survey conducted for all students at our home institution, and to enhance participation as much as possible.

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