The Role of Undergraduate Research in Engineering Education

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Abstract

The establishment of formal research programs for undergraduate engineering students is one way to encourage critical thinking, life-long learning, and the pursuit of graduate education. This paper discusses issues associated with the participation of undergraduates in engineering research, and describes the highly successful and firmly established EXCEL Scholars Program of undergraduate research at Lafayette College. Potential modifications and enhancements will be presented which are proposed to enable the program to meet the changing needs of the students and graduate schools. The information contained in this paper will serve to inform other institutions considering the initiation or expansion of a program of undergraduate research.

I. Introduction

Many factors affect an undergraduate engineering student's decision of whether to join the workforce or pursue graduate studies and a research oriented career upon graduation from college. For example, the strong economy in recent years has created a huge demand for graduating engineers. This in turn has resulted in enhanced industrial recruiting efforts which often give students the impression that an undergraduate education is both the necessary and sufficient answer to career preparation. In comparison, full-time graduate study leading toward a research oriented career often appears far less attractive than the immediate and highly visible rewards offered for specific entry level engineering skill sets. As a result, the number of engineering graduate degrees awarded has dropped in recent years[1].

While direct entry into a graduate program is not for everyone, it must be encouraged for the nation's top research-oriented students to ensure sustained technological innovation. In order to encourage our most promising scholars to consider graduate school, factors that discourage them from doing so should be recognized and addressed. In addition to corporate and peer pressure to immediately enter the workforce, many students have a negative perception of the economic consequences of this decision. They often believe that the best economic return will be obtained by going directly into the workforce and that pursuing graduate studies will cost too much in both tuition and lost wages. Many of

our students, including those at the top of their class, are unaware that they can attend graduate school for free and, in fact, with compensation as either a teaching assistant or research assistant. Although they know how to do the calculation, they have generally not performed an economic analysis to assess their life-long earning potential and they frequently fail to consider quality of life issues associated with the enhanced career options available to those with a graduate degree. For women engineers, the differential impact on family life must be a part of the analysis[2]. Therefore, as a first step, students should be informed of all of the options available and their economic and quality of life implications.

It also has been observed that many, if not most, of our best students have multiple opportunities to obtain internships or paid work experiences with engineering firms. The students often find these experiences extremely enjoyable, especially when they are encouraged to apply their technical skills to a current real-world problem. Are there any corresponding experiences that can be offered to these same students to show them the excitement of graduate school? Perhaps if a student has the opportunity to perform challenging undergraduate research, that student's appetite for graduate studies and a career in research will be whet. More generally, experience suggests that undergraduate research improves the quality of the education for the vast majority of the students who participate regardless of what type of career they ultimately pursue.

Both industry and ABET are stressing the importance of improved critical thinking skills and a passion for life-long learning[3]. But in a hiring climate in which the basic skill sets mastered at the undergraduate level are perceived by students to be all the preparation required for a successful career, how effective are arguments for the importance of lifelong learning? How should undergraduate engineering programs respond? Again, part of the answer may lie in the further proliferation of formal research programs for undergraduate engineering students. Indeed, undergraduate research has the potential to better prepare students in the areas of both critical thinking and research methods as encouraged by both industry and ABET. Furthermore, a meaningful undergraduate research experience provides an excellent opportunity for students to learn about both the realities associated with, and the opportunities resulting from, a graduate engineering education, thus better motivating them to pursue advanced studies. In addition, with respect to lifelong learning, students quickly realize that researchers must constantly stay abreast of the rapid progress in their area or they will be unable to compete for contracts and grants. The useful half-life of an engineering degree is generally acknowledged to be shorter than the life of an engineering career.

The remainder of this paper will illustrate the value of an undergraduate research program by using the highly successful and firmly established EXCEL Scholars Program at Lafayette College as an example. The illustration will explain the administrative structure of the program, list the number of students involved, describe the types of projects undertaken, show examples of the results of joint student-faculty scholarship, and provide data on the impact of the program on placement of students in engineering graduate programs. In addition, several issues that have arisen due to the increased demand for participation in this program will be discussed along with potential

modifications and enhancements to improve the student undergraduate research experience. The information contained in this paper will serve to inform other institutions considering the initiation or expansion of a program of engineering undergraduate research.

II. Excel Scholar's Program Description

Lafayette College is an independent, coeducational, residential college of 2,000 students and 182 full-time faculty, with approximately 20% of students and faculty being in the Engineering Division. The College's mission states that it "strives to develop students' skills of critical thinking, verbal communication, and quantitative reasoning and their capacity for creative endeavor; it encourages students to examine the traditions of their own culture and those of others, to develop systems of values that include an understanding of personal, social, and professional responsibility, and to regard education as an indispensable, life-long process." The curriculum is distinguished by degree programs in liberal arts and in engineering, offering the Bachelor of Science in 4 engineering fields and 8 scientific fields and Bachelor of Arts in 25 major fields of study. Historically, Lafayette College has an excellent record of placing students in top engineering graduate programs. Among non-Ph.D. granting institutions, Lafayette ranks number one nationally in the number of engineering students who go on to complete the Ph.D.[4]. The EXCEL Scholars Program, the primary vehicle for undergraduate research at Lafayette College, has enabled many of the participating students to gain valuable research experience which in turn has given them excellent opportunities to go on to graduate school. Further, this formal program enables the College to sustain its strong record in graduate school placement. The program was started in 1986 with fourteen students. Now a $250,000 per year program, it supports approximately 100 students each year in high quality undergraduate research projects. Support for EXCEL comes not only from outside faculty research grants but also from endowments, private foundation grants, and College funds. It is open to students in all majors at the College who have completed their first year of study and have achieved a GPA of at least 3.0/4.0. The program is particularly popular among students in engineering and the natural sciences. Approximately 25 engineering students per year participate in this program; this equates to 20% of eligible students (as defined previously) or 6% of all engineering students. About half of the 34 engineering faculty (Chemical, Civil, Electrical and Computer, and Mechanical Engineering Departments) at Lafayette are involved with EXCEL scholars each year. Approximately 40 students in the Natural Sciences, 20 students in the Social Sciences, and 10 students in the Humanities participate in the EXCEL Program each year.

If interested, it is the student's responsibility to seek out a research partnership with a faculty member although on some occasions the faculty mentor may initiate the conversation. Much of the information about the research opportunities and faculty participants is passed by word-of-mouth either from student to student or through informal lunchtime presentations with food provided by the sponsoring engineering department. If a faculty member agrees to work with a student, the faculty member

submits a proposal to the Faculty Academic Research Committee, which meets once each month to review the proposals.

Each proposal presents a description of the student research and formally requests that the college fund the student's efforts; the current student compensation rate is $10 per hour. Students may work full-time during the three months of summer and the three-week January interim session. They also may work 8-10 hours per week during the academic year. With year-round work, up to $7,500 may be earned. The vast majority of the EXCEL proposals are approved unless the proposal is incomplete or the student does not satisfy the minimum GPA requirement (3.0/4.0). Virtually all interested faculty are able to obtain funding for one EXCEL scholar while the availability of funds for additional students for a faculty member depends on the relative demand. More than one student working on a research project allows the opportunity for student collaboration as an additional benefit. Once approved, the students work with the faculty member for a specific period of time, ranging from a semester to a calendar year. If a student and faculty member want to continue to work together, the original proposal can be resubmitted with a letter requesting continuation of the work. Historically, most of the student participants have been juniors and seniors with much of the research activity taking place during the summer between the students' junior and senior years and during the winter interim of the senior year. Within the engineering division, typical student responsibilities include literature searches and reviews; equipment design, construction, and calibration; experimental design; data accumulation, data compilation, and initial interpretation of results; contributions to theory and model development; and the preparation of portions of publications.

III. Student Outcomes And Accomplishments

The students participating in the EXCEL Scholars Program have had a wide variety of successful outcomes and significant accomplishments. Many EXCEL scholars have presented their research results at the National Conference for Undergraduate Research. In addition, some students have presented the results of their work either solo or jointly with their faculty mentor at either regional or national professional conferences, usually in the student paper sessions. A select few of the EXCEL scholars have published co-authored papers with their faculty mentor in professional refereed journals. Other students have filed for and received patents for the work conducted under this program. Several of the scholars have won national scholarships from the National Science Foundation and the Department of Defense and other prestigious awards including a Fulbright Scholarship.

While Lafayette has only recently begun to acquire institutional data on the results of EXCEL scholar projects, the authors have mentored a significant number of students over the past 10 years and believe our collective results are fairly typical. Of the 23 EXCEL Scholars mentored, 15 have gone directly to graduate school (Georgia Tech, Lehigh, MIT, Stanford, UC Berkeley, Cornell, University of Florida), 16 have presented their work at regional or national conferences, and 6 have been a co-author on a refereed journal article.

IV. Excel Program Issues

The EXCEL Scholars Program has been very successful from both a student and faculty perspective. Student participation has increased from 23 students in academic year 1987-1988 to 112 students in academic year 1999-2000. Student co-authored publications have increased from 29 in academic year 1987-1988 to 51 in academic year 1998-1999. However, a number of issues requiring attention have been identified in recent years. Most concerns revolve around the inability to involve all engineering students who express an interest. This is a multi-faceted problem which is affected by increased student interest, limited faculty participation, finite resources, and academic regulations. Each factor will be briefly discussed.

Increased Student Interest:

In recent years the students have received information about the EXCEL program as part of the College recruiting process. As a result, interest among both first year students (for participation in the summer between their first and second year) and sophomores has increased to the point where not all potential scholars can find a willing faculty mentor. While participating faculty recognize the reality of resource constraints, most believe that the benefits of the program warrant a search for ways to permit increased numbers of student participants. To increase the number of EXCEL scholarship opportunities, Lafayette must identify additional funding sources and either increase the number of faculty participating in the program or increase the average number of students working with each faculty mentor.

Faculty Participation and Issues:

It must be recognized that although undergraduate students usually are able to perform valuable time saving tasks in the laboratory, it takes a great deal of faculty time to prepare the EXCEL proposals, to bring the students up to speed on the technical aspects of the research, and to train the students in the use of appropriate experimental and analytical techniques. That is, the institution must understand that while faculty members are receiving the benefit of increased research productivity, they are (willingly) paying a price in terms of time spent training their student colleagues. In addition, it has been observed that most of the participating faculty are either Assistant Professors or younger Associate Professors. Thus, in order to increase the number of EXCEL opportunities it will be necessary to identify and implement incentives to broaden the faculty pool and to minimize the administrative burden placed on participating faculty.

The majority of the faculty interviewed felt that the EXCEL program is viewed by the administration as a faculty perk since the faculty are getting “free” student help. In contrast, the faculty view participation in the program as a break-even proposition. On average, the faculty time spent helping a student learn about the research project is roughly balanced by the faculty time saved in the laboratory. If the EXCEL program is viewed as a student benefit (part of the education experience) then it may be reasonable

to grant teaching credit to faculty who supervise a certain number of projects over a period of time. Since the EXCEL mentoring role is in large part a teaching activity, it should be recognized as such. However, this paper is not advocating that the program be a means to reduce the traditional teaching load since, due to the limited resources at a small school like Lafayette, it is difficult to grant course releases and simultaneously maintain both the breadth of courses offered and small class sizes. Therefore, alternative ways to reward faculty for the teaching they do as EXCEL scholar mentors need to be identified and evaluated. Possibilities include one or more of the following: enhanced travel grants, modest funding for laboratory development, release from service (committee) responsibilities, or small stipends.

Academic Regulations Issues:

Another area of concern involves the non-uniform student workload under the EXCEL program. As mentioned previously, most of the actual work is conducted during the summer and over the winter interim session even though the research program often covers the full academic year. Though this is not scheduled per se, it results from the inarguable fact that the students are often too busy with a heavy course load during the semesters to spend a significant amount of time working on the EXCEL research. This situation needs to be recognized by faculty supervisors, and taken into account in EXCEL program schedules, especially as the program continues to grow. Two alternatives have been identified. First, in an ideal EXCEL project there are aspects of the work that can be conducted over the course of the academic semester without impinging on the student's other course work. For example, it is often possible to use the academic year to collect data without any substantial effort to interpret the results. Structuring projects in this manner gets the busy work out of the way when student intellectual efforts should best be focussed elsewhere and yet positions the students for optimal productivity during the interim and summer sessions.

Second, institutions could consider granting elective course credit for student research. To date, Lafayette College has resisted this option -- a long-standing College policy has been that students should receive either academic credit or pay, but not both, for any given educational activity. The option available to students who prefer to receive academic credit is to enroll in an independent study course rather than in the EXCEL program during the academic semester. Although the existing model is reasonable, it does have some disadvantages. Faculty mentors who have multiple students moving into and out of a continuing research program find themselves writing what many believe are redundant EXCEL proposals. In addition, many of our students must find alternative ways to make money when the EXCEL funds disappear and so take jobs shelving books in the library or working as a groundskeeper. This option is not necessarily in the best academic interests of the students. One alternative would be to make the pay rate for scholars receiving academic credit for their work comparable with the pay rate for a less academically rigorous job rather than the standard $10/hour EXCEL rate.

A similar consequence of Lafayette's decision that research can be for pay or for credit, but not both, is that some of the very best students are forced to decide in their senior

year whether they want to pursue a non-paying senior honors thesis or an EXCEL research project. This decision is particularly difficult for students who must earn money to meet their financial commitments. One potential solution again would be to change the regulations to make them less limiting. For example, if a faculty member has grant funding available that could be used for honors thesis research, these funds could be used to compensate the student for the honors research efforts. Of course the financial aspect of the problem becomes moot if pay rates for scholars are adjustable as suggested at the close of the previous paragraph. Another aspect of the EXCEL/Honors project dilemma is that honors projects are meant to be a reflection of independent thinking by the student while EXCEL projects are often extensions of a faculty member's long-term research plan. To be consistent with honors thesis requirements, an EXCEL project which is also to be counted as an honors project would have to meet the same standards for student originality (to be judged by the faculty committee overseeing the project) as would any other honors project.

Other Ways to Expand Student Participation:

Beyond the immediate requirement to modify the EXCEL Scholars Program to meet increased student demand, several other suggestions have been made to enhance the program and further increase student involvement. First, to enable students to be involved in EXCEL research throughout their academic career, the program should be made even more accessible to freshman and sophomores. One possibility for doing this is to add a second "tier" to the program specifically geared towards first and second year students. The projects for this part of the program could be geared to introduce the students to research and prepare them for the more intense EXCEL research experience. In particular, the benefits of involving some of our best students in this program early in their undergraduate careers are significant. The earlier students start working with faculty mentors, the more involved they can become with the research efforts. Although there have been some exceptions, the majority of the student-faculty co-authored papers result from multi-year partnerships. The students could be compensated at a rate similar to that paid by non-academic jobs as described earlier.

Second, if the EXCEL Scholars Program is successful in whetting a student's appetite for further learning, and if the EXCEL experience does enable the student to get accepted at a graduate school, there may still be a piece missing – what options are available to the student during the summer between graduation and the start of the first graduate semester? One suggestion is to expand the EXCEL program to make graduate-school bound students eligible for compensation for working on a research effort over the summer following graduation. As with the current EXCEL requirements, the student would have to identify a cooperating faculty member and a proposal describing the research effort would have to be submitted; the most likely scenario is a continuation of the undergraduate EXCEL student/faculty partnership. A significant benefit of this program enhancement is that the student has more knowledge and research experience now than at any other prior time thus potentially enabling the student and faculty mentor to accomplish a great deal. In addition, depending on the student's planned course of graduate study, the student may be able to get a head start on the graduate research effort.

It might be necessary to assign proposals for this type of project a lower internal funding priority than those designed for students who have not yet graduated in order to make optimal use of limited funds.

V. Conclusions

The student successes resulting from the Lafayette College EXCEL Scholars Program provide strong support for a number of conclusions. First, formal undergraduate research programs have the potential not only to whet an undergraduate student's appetite for full-time graduate studies but also to instill all involved undergraduate students with improved critical thinking skills and an appreciation for life-long learning. Indeed such a program has the potential to improve the quality of the education for the vast majority of all students who participate thus making them better prepared regardless of what type of career they ultimately pursue. While the information in this paper can most obviously aid other undergraduate institutions interested in forming or expanding a formal undergraduate research program, it also may benefit institutions with graduate programs. In fact, given the declining graduate program enrollments in recent years, the information presented in this paper may help such universities to initiate their own undergraduate research programs or develop partnerships with undergraduate institutions and thus boost graduate enrollments with students that already have experience in performing challenging research.

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