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Undergraduate Research Models Applicable for Geotechnics

ABSTRACT

The projected, increasing gap between expected workforce staffing needs of those with science technology and engineering (STEM) training and the anticipated graduates with STEM degrees demands a re-examination of how to increase the number of STEM students graduating and remaining in STEM careers. Given the continued acute under-representation of women and some racial minorities, these groups warrant additional consideration, as their further engagement may help fill the shortfall. In debates and research surrounding these challenges, the issue of retention has received relatively little investigation both in terms of bachelor's level retention for degree completion and longer-term retention within STEM activities (either educational or industrial). Anecdotal information would indicate that undergraduate students engaged in research are more likely to complete their degrees, improve their grades after participation, enroll in STEM-based master's programs, and remain in STEM careers. This paper outlines various models for undergraduate engagement in geotechnical research, as a means to develop curricular and non-curricular, short- to medium-term opportunities to promote such efforts.

INTRODUCTION

This paper provides an overview of five models that the author has used in undergraduate geotechnical research. Because institutions, student populations, curricula, and general resources (faculty time, as well as direct funding) differ, some may be more practical for adoption and/or adaptation than others at specific institutions.

BACKGROUND

The recruitment of domestic undergraduates into science and engineering graduate programs has long been identified as a problem. The situation is especially acute with respect to the involvement of under-represented groups, particularly women, Hispanics and African Americans. Many cultural and structural impediments have been identified as contributors to the situation ranging from attitudes towards science and math at the elementary and secondary educational levels, to a lack of identifiable mentors from these under-represented groups at the university level. Trying to change many of these factors is difficult, especially since they are largely focused at the pre-tertiary education level and relate to deeply-rooted cultural and educational issues. The question then becomes, whether there are specific things that can be done that circumvent existing impediments to improve the likelihood of graduate school enrolment and/or continued involvement in civil engineering once students have reached the bachelor's level. In a sub-field such as geotechnical education where a master's degree is the preferred entry degree by most international firms and demand has remained strong for such candidates through the recent recession (e.g. in tunneling and mining), these concerns are particularly relevant.

Many institutions have implemented innovative efforts targeted at under-represented freshman and sophomores during the critical early college years, with the main focus being on baccalaureate degree completion. This has mostly been achieved through multi-disciplinary efforts, residential programs, and supplementary advising, but integrating research opportunities has not been a traditional component to this. However,

to more specifically promote post-baccalaureate education in science and engineering for all students, there have been efforts to create small-scale, short-term, undergraduate research opportunities. Much of this has been funded through the National Science Foundation's (NSF) Research Experience for Undergraduates (REU) program. NSF-funded opportunities occur either as a supplement to a sponsored research program, where 1 or 2 students join a graduate-level research initiative, or as a standalone summer program, where approximately one dozen students participate at a single site for an intensive 8-10 week program, and all students conduct individual or paired investigations related to a single research theme. Despite well-documented benefits, such as those described by Hunter et al. (2006) on improved personal and faculty-mentor perceptions of "becoming a scientist", four main problems arise from this type of arrangement. The first is that the percentage of students able to participate is highly limited impacting far less than 1% of all civil engineering students. Consequently, the likelihood that such an approach will have a long-term impact on the numbers of graduates completing STEM degrees and having STEM related careers is extremely low.

The second problem is that studies show that students who participate in these programs are already high achievers (as these posts are awarded competitively) who are, thus, already likely to complete their degrees and continue onwards. The work by Russell et al. (2006), which involved the survey of 15,000 individuals (including past undergraduate student researchers and their supervisor(s), plus undergraduates who were not student researchers) concluded that among both NSF and non-NSF funded undergraduate research that the undergraduate participants tended to be high achievers, with relatively high grade point averages and early expectations of obtaining an advanced degree. Furthermore Russell et al. (2006) found that those who participated in undergraduate research were twice as likely as those who did not do research to have pre-college expectations of obtaining a PhD. Additionally, work by Loppotto (2004) in a survey of 1,500 past undergraduate researchers showed that at best there was 5% gain in self-identification of "likely to do a Ph.D." over those previously disposed to. Neither study considered master's degrees. The third issue is that the students are already juniors, if not seniors. Thus, they are past the high-risk point of abandoning their degrees. Interestingly, most students who drop out decide to do so in their first semester, even though many postpone the actual decision in later that year or their next year and relatively small changes in the curriculum could have significant implications (Laefer, 2009). Finally, with the summer REU programs, although the experience is intensive, because the students tend to participate away from their home institutions, the ability to provide significant, follow up mentoring is limited.

RESEARCH MODELS

Arguably, to impact STEM retention within the degree years and beyond, alternative models are needed. Ideally, these model would be more integrated with the student's home institution and available to more students. To understand the potential benefits and difficulties with the administration of such models, the author is presenting 5 various models with which the author has had extensive first-hand experience over the past 15 years and represents the anecdotal wisdom gained from the participation of approximately 200 students during that period.

The five proposed models are the following: (1) the summer program (like that currently supported by NSF); (2) the final year project; (3) the elective course; (4) laboratory assistance; and (5) intersession internships. Many researchers are familiar with the

first two as they are commonly available in many institutions. Those with NSF grants and other institutional incentives may be common participants of option 4, but option 3 (the elective course) and option 5 (the intersession internship) are quite rare in STEM programs. Most of the aforementioned programs are self-evident, but the intersession internship may not be. It is a short-term, intensive research opportunity, where the students work full-time for 1-3 weeks as an introduction to hands-on research. Each program will be described below in five general categories: participation characteristics; organization, incentives and outcomes, funding needs and options; and advantages and disadvantages.

Participation Characteristics

Participation characteristics vary quite widely across the models (Table 1), with durations lasting as little as 1 week, as in the case of the intersession internships, to lab assistance, which may have an indefinite duration often spanning several semesters, if not years, if the student begins early in his or her academic career. Interestingly, while Russell et al. (2006) found no evidence of a superiority of summer programs over academic-year programs, or vice versa, a strong correlation was found related to the duration of the student's participation. While duration is something that is often dictated externally by the length of a semester or the quantity of funding, Russell et al. (2006) reported it as one of the most influential factors for self-aspiration of a Ph.D. They reported that among the undergraduate researchers in their extensive study, 30% of those with more than 12 months of research experience reported that they expected to obtain a PhD, compared with only 13% of those with 1 to 3 months of research experience. While this figure does not correct for the fact that those who did not like research did not remain doing the research or did not pursue further research activities, it does imply a certain positive effect of longer research projects better reinforcing educationally-based retention (Figure 1). The 12-month figure is an interesting one, as NSF will not permit REU funding for students who have just completed their degrees. Thus, the assumption is that many of these students began prior to the summer following their junior year. Anecdotally, many researchers show a strong disinclination for taking students prior to this final summer because of the absence of relevant or advanced coursework.

The intensity of participation is also a factor. Summer breaks and other intersession periods permit full-time engagement, with term-time involvement often controlled by the quantity and nature of the course-work (if any) occurring at that time. In general, although students could work as little as an hour or two a week, for the sake of consistency and to make it worth the supervisor's time generally a minimum commitment of one day per week during term time (or 10 hours, if the shift must be split) is needed for meaningful participation. Similarly, given the often more intense nature of research during the summer, the home lab's training efforts may not be adequately compensated, if the student is not working at least 20 hours per week during the summer period.

Depending upon whether participation is mandatory, as is the case for the final year project, the supervisor may need to actively recruit. In the case of elective course work or lab assistance, typically the supervisor already has some type of relationship with the student, either from a class or some mentorship role (e.g. faculty-in-residence in a dormitory, faculty sponsor of a student organization, or as the assigned faculty advisor for coursework selection). In the case of the summer program, a national recruitment effort may be expected by the funding agency. Otherwise a broadcast email is often highly effective. The local economy may, however, dictate the extent of distribution to achieve the right balance between good recruitment and being overwhelmed with applicants.

Table 1. Participation characteristics

	Duration	Intensity	Recruitment
Summer Program	8-10 weeks; not generally renewable	Full-time (35-40 hrs/wk)	If NSF sponsored, generally national recruitment is expected
Final Year Project	Typically 1 term (8-15 weeks); on rare occasion multiple term participation (16-30 weeks)	Maybe as little as 10hrs/wk up to full-time depending upon other course work obligations	Mandatory
Elective Course	Typically 1 term (8-15 weeks); on rare occasion multiple term participation (16-30 weeks)	Typically the equivalent of a single course (approximately 10hrs/wk)	Generally invitation only given to students showing interest in the subject
Lab Assistance	Open ended; dependent upon funding and student status at start of research. Typically 1 semester minimum; summer tends to be better, especially for incoming students	Generally full-time (35-40 hrs/wk) during the summer and part-time (8-10 hrs/wk) during term time	Either the same as the elective course or as a general advertisement across a certain sector of the student body via email
Interession internship	1-3 weeks	40 hours minimum (70 is preferred over the course of participation)	Usually a broadly sent email which may extend to affiliated programs and even graduate students in taught programs

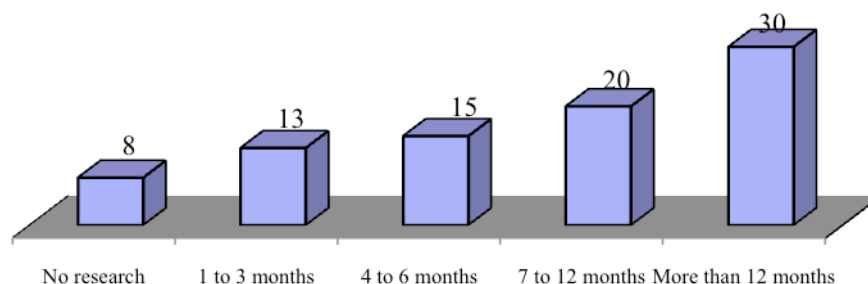


Figure 1. Percentage of Undergraduates who expected to obtain a Ph.D. based on level of participation in undergraduate research (data from Russell et al. 2006).

Organization

The structure of the research project is largely dependent upon the duration and intensity of the student's participation (Table 2). In a summer program and always in final year projects or other arrangements for academic credit, there must be student ownership of a distinct portion of the research. This is true, even if the student is partnered or part of a small group. When student participation is highly short-term or for pay, as in the case of the interession internship and lab assistance, respectively, the students are more often accommodated in an assistantship or apprentice type role, where very small projects or pieces of projects are given to them. In these cases, it would be highly unusual for the student to be doing a literature review, unless that was their only assignment. In the other cases where there is project ownership, some type of literature review would be expected.

Irrespective of the nature of the work, a key recommendation of Russell et al.

(2006) is the involvement of the student in the larger culture of research. This may range from participation in weekly laboratory meetings with a broader group of researchers, attending academic lectures, or even participating in local or regional conferences, as these have been more strongly related to positive outcomes than having completed assignments such as research proposals, reports, or poster presentations.

Table 2. Participation organization

	Structure	Supervision
Summer Program	Student often has ownership of a single project that is affiliated with a group of other projects or a small piece from a larger project	Under either faculty member or senior graduate student/post-doctoral researcher
Final Year Project	Student works alone or with partner	Directly with faculty member, although under exceptional circumstance under the direction of a post-doc or senior Ph.D. candidate
Elective Course	Student works alone, with a partner, or in a small group (4 maximum)	Same as Final Year Project
Lab Assistance	Student works in a large group setting in a lab or in the field	Generally under the day-to-day guidance of graduate students
Intersession internship	Same as Lab Assistance	Same as Summer Program

Supervision differs somewhat by program model (Table 2). Where academic credit is being earned, it would be considered highly irregular at most institutions, if the supervisor was not a faculty member. In the other cases, including the summer program, the pairing of the undergraduate student with a graduate student or post-doctoral researcher can be highly beneficial for student and supervisor: (1) more direct feedback student receives, (2) bonding with someone closer in age and academic achievement, and (3) experience for the supervisory researcher. The one possible exception is in the intersession internship, where participation is highly intensive and short-term. In this case, the faculty member is often using it as a means to gain a large, short-term work force for large laboratory efforts or fieldwork (e.g. a significant concrete pour) or plans to do hiring in the near future for either more undergraduate work or for a master's position. In those cases, the shoulder-to-shoulder, day-to-day contact with the new recruits provides invaluable feedback to the faculty member. Furthermore, graduate students may be overwhelmed trying to quickly acclimatize several new students in a short period of time. In those cases it is helpful to have all student participants for the week(s) begin their commitment at the same time. This enables the faculty member to provide a comprehensive introduction including performance expectations and safety training (where appropriate).

While mentor enthusiasm has been shown to be a crucial factor in a student's reported satisfaction level, Russell et al. (2006) reported no evidence that minorities benefited more from same-race/ethnicity mentors than from those of a different race/ethnicity or that women benefited more from female than from male mentors. However, over time, having a diverse group of mentors appeared to be mildly beneficial to all respondents.

Incentives and Outcomes

Incentives for participation may vary widely across the programs and for individual students (Table 3). While the project is mandatory for the "final year project", other students seeking enrichment and not needing payment may also desire to do the research for academic credit. This is also possible for those in summer programs, although those

students like their counterparts in lab assistance are typically paid for their efforts. Generally only the intercession interns are volunteers seeking to build their resumes and possibly garner a letter of recommendation. In large, public universities, students often have little extended contact with faculty members. Thus, getting letters of recommendation for scholarships, graduate school, or even employment may prove challenging. Consequently, many students see this as a way to overcome that obstacle.

Table 3. Participation incentives and outcomes

	Academic credit	Financial compensation	Outcomes
Summer Program	Possible but generally not given	Usually a fixed weekly or monthly bursary	Typically a short report
Final Year Project	Yes	None, although follow-on hourly employment might be encouraged for writing up the work in a publishable format, if appropriate	Typically a lengthy report that may become the basis for a conference (or even in exceptional cases a journal paper)
Elective Course	Yes (may be done as pass/fail)	Same as Final Year Project	Typically a lengthy report
Lab Assistance	None	Hourly pay; a problem may arise that during the summer, even at a fairly modest rate the participants may be earning more than the full-time, regular graduate student stipends	None
Intercession internship	None	None	None

When financial compensation is given, it is generally at some rather low level, often less than \$10/hour. However, in urban areas wages may be more competitive. One problem with paying students hourly basis is that when they work in the summer, if they are working 40hrs/wk they may earn more than the graduate students ($\$10/\text{hr} * 40\text{hrs} * 4.5\text{ wks} = \1800). Those receiving compensation from a funding agency are usually asked to write a short report on their experience. Depending upon the agency, this may be highly structured or rather open-ended. Where, however, academic credit is involved, it is highly preferable to have a set of written guidelines. This minimizes any misunderstandings and provides a guidance document for assessing any academic appeals. For final year projects, guidance is also often provided on length (e.g. 50-100 pages plus appendices). Where the project is worth only the equivalent to a single course a 20-25 page report may be more appropriate than something more lengthy.

Funding Needs and Options

Funding needs are largely driven by whether or not the student is being paid (Tables 3 and 4) and the nature of supplies required for the work. With final year projects, there is often an ambiguity as to what costs (if any) are the student's responsibilities. This is something that should be clarified at the beginning to prevent later misunderstandings. Often the projects are in support of existing research efforts, and funds can be used to cover the affiliated costs. However, many faculty members use undergraduates to do small pilot programs to test ideas or to collect preliminary data to support a funding application. In those cases, institutional funds of some sort will have to be sought. Alternatively, there are often small undergraduate research programs sponsored by the home

university or other organizations that have a low-level of funding affiliated with it for laboratory supplies (typically no more than \$500 per student or per project). There may also be special institutional funds set up specifically to support undergraduate research and faculty members (especially new faculty members) should explicitly ask about their existence. Another option is when there is already a good student who the faculty member wants to bring into the lab. There are numerous program that the student can apply for individually with a letter of support from the faculty member. These are typically industry- or area-specific and generally require a short research proposal (1-2 pages).

An often untapped source of potential funds is the U.S. Federal Work-study Program (FWP 2010). These funds are part of a student’s financial aid package and are, thus, not transferrable to another student. Generally, the faculty member contacts the work-study office and proposes a position for a certain number of hours per week at a particular pay-scale. That is then advertised among financial aid eligible students. How these funds are administered varies widely from institution to institution. In some cases there is no charge to the faculty member. In other cases there is effectively a “co-pay”. For example, if the position is advertised at \$10/hour, the faculty member may have to pay 25%. Finally, there are campuses where the faculty member must pay the entire amount. In those cases, there is no benefit for the faculty member (except free advertisement), and there are the additional downsides of further paperwork and the limited applicant pool, as not all students are eligible for work-study funds. Furthermore, in some communities where jobs are plentiful, students may opt for off-campus positions and request that the work-study portion of their aid allocation be converted into a long-term, student loan. In communities where employment is harder to find, posts of any kind may be highly competitive. Although the work-study program is not a suitable solution for all undergraduate research funding needs and it does not come with a supplies’ budget, faculty members may use it to stretch existing funds, especially if there are good students already engaged in research who can be taken off a grant and paid through these other means.

Table 4. Funding needs and options

	Need	Options
Summer Program	Wages and supplies	Work study, special institutional funds, grant, NSF-REU, special NSF-REU programs fund and other summer funding for STEM recruitment
Final Year Project	Possibly supplies	Supplies may be from institutional funds, faculty designated resources, or from funded research, if this is in support of a larger project
Elective Course	Supplies	Same as Final Year Project
Lab Assistance	Wages and supplies	- Wages from work study, special institutional funds, grant, NSF-REU - Supplies typically from larger funded project for which the student’s efforts are supporting
Intersession internship	Supplies	Supplies same as Lab Assistance

Advantages and Disadvantages

Each model of undergraduate research offers distinct advantages and disadvantages (Table 5). While the summer program option offers a period of relatively uninterrupted productivity, a chance to get to know students well, even ones recruited from other institutions (for the purpose of future recruitment), there are also drawbacks. These in-

clude that these students expect payment, relatively few students can participate, and that their supervision may curtail faculty summer travel plans.

The final year projects offer a ready supply of students to investigate new ideas and conduct pilot projects, without having to find funding. That approach is also the only mechanism that ensures all students get to participate in some form of research. It may also be a mechanism to recruit master's students. However, many of the most promising students have often already committed to a graduate program or employer. Furthermore, while some students are highly motivated and capable of generating award-winning work, others are only interested in passing and not jeopardizing their other grades. Consequently, the faculty member's time (from a research productivity perspective) may not be well-spent. Such supervisory efforts may be significant, if the graduating class is large and student:faculty ratios are high. As well, the work must be done as part of the curriculum (unless offered as a summer requirement) and is often hard to fit into the curriculum until the final semester. Finally, these projects are often done in pairs, where all of the partner-based risks occur, in terms of a lack of teamwork and personal disagreements and difficulties in determining individual contributions.

The elective course option is similar to the final year project, but it tends to be less resource intensive. The converse of that is that the output is generally significantly less, because the time commitment is smaller. Because it is not mandatory, it can be done in any term including the summer one, at either the beginning of a student's research participation or the end of it. One of two major downsides is that students often have difficulty managing their time, and research can easily become all-consuming, often at the expense of other studies. The other is the lack of predictability of enrolment levels, as the program tends to be highly ad hoc in nature.

The model of hourly laboratory assistance tends to fully integrate a student into a larger lab group, assuming that there is one, with graduate students/post-docs capable of supervisory roles. While the model is quite common in the biological sciences, relatively few civil engineers operate with a large common group either as a function of the type of projects or the absence of large-scale funding. Consequently, there are few opportunities for students to participate in such a program. While a major benefit is that a young student may join the research early in his or her academic career and grow in responsibility in the lab, there may be little independent work that the student can point to as his/her own. This also may complicate the benchmarking of the student's achievements, as this model rarely has a substantial independent piece of work as an outcome.

The least common model is the intersession internship. Some advantages include that it can be done during any intersession for as little as one week, can involve younger students, and can accommodate a large group of students [this author has worked with as many as 20 students running them in 2 shifts per day (7:00-3:00 and 2:00-10:00, with meals taken on-site)]. Additionally, a large work force can be brought together for a short-time with relatively little investment on the part of the faculty member. This enables the faculty member to get to know in a meaningful way a group of students, who can fairly quickly be vetted for potential future employment or for recruitment into a graduate program. As the internship can be opened to students at all stages and a variety of affiliated disciplines, the resulting group can be highly eclectic often generating ties to other departments and surprisingly good and innovative results as there is a cross-fertilization of techniques and approaches.

Table 5. Advantages and disadvantages

	Advantages	Disadvantages
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Summer Program	<ul style="list-style-type: none"> - A relatively uninterrupted period to get to know the student - Often a chance to do national recruitment - Typically a screening mechanism for potential master's/doctoral students 	<ul style="list-style-type: none"> - Relatively few students have the opportunity to participate - Funding for student wages must be found - May truncate summer travel plans if alternative supervision is not available with the lab and/or if student is not sufficiently independent
Final Year Project	<ul style="list-style-type: none"> - Ready supply of students to investigate new ideas and conduct pilot projects, without having to find funding - Full student body participation - Some students are extremely motivated - Can generate publishable or near publishable data - May be a mechanism to recruit good master's students 	<ul style="list-style-type: none"> - If done with a partner, all of the partner-based risks occur in terms of a lack of teamwork and personal disagreements and difficulties in determining individual contributions - Hard to do except in final year - Requires significant faculty commitment, as all students in a graduating class must be supervised, if the project is mandatory (could be done as an option to some capstone design course) - Students may not be highly motivated - Time must be found in the curriculum - Funds for laboratory supplies not readily available - Promising students have often already committed to a graduate program or employer
Elective Course	<ul style="list-style-type: none"> - Can be done in the summer - Can be done in any term - Can be used as for pilot projects or as an outgrowth of paid hourly lab assistance 	<ul style="list-style-type: none"> - Students become all consumed by the research and have difficulty balancing their other obligations - Unpredictable enrolment levels
Lab Assistance	<ul style="list-style-type: none"> - Students can be brought in very young, kept, and nurtured for most of their academic career 	<ul style="list-style-type: none"> - Little independent work - Few projects and faculty research programs in Civil Engineering are well-suited for this - Relatively few students have the opportunity to participate - No means to benchmark work - Graduate student(s) may not be up for the challenge
Intersession internship	<ul style="list-style-type: none"> - Can be done during any intersession - Provides an instant vetting of potential graduate students - Is a low commitment in terms of time and funds to get a large group of enthusiastic workers - Can yield some highly surprising positive results and students - Often attracts students from other departments and programs giving an interdisciplinary aspect to the work and often results in building ties outside of the department 	<ul style="list-style-type: none"> - Requires a significant amount of organization - Precludes participation in nearly anything else during the period - Comes at the loss of an intersession break to catch up on rest or backlogged projects.

The main disadvantages relate to the highly intensive commitment needed by the faculty member just before the internship and throughout its duration, as the students must be kept highly busy, therefore requiring significant pre-internship organization and purchasing. Similarly, the intensity of the experience precludes participation by the faculty member in nearly anything else during the period, which is sometimes difficult and

comes at the loss of an intercession break for the faculty member to catch up on rest or work-related obligations. To accommodate the need of many students to earn money during the intersessions, it is possible to run the program 7 days a week and allow discontinuous involvement (2-3 days on and then another 2-3 days off). Half-days should be discouraged based on the highly group-nature of the work. If unavoidable, it is better to have the student start in the morning and leave the team at the lunch break.

CONCLUSIONS AND PERSONAL OBSERVATIONS

Five quite disparate models for undergraduate research are presented. The viability of any must be considered with respect to the goals of the supervisor, the aims of the academic program, and the regulations of the institution. The author's experience with approximately 200 students across these 5 programs is the following:

1. Only the Lab Assistance approach had any clear correlation with large-scale, post-graduate enrollment. In that case 60% of participants pursued post-baccalaureate degrees (more than double the institutional average with minorities and women enrolling at four times the institution's average).
2. Many students who excelled at the final year project were female, even though their coursework to date had not been exceptional.
3. Those whose course work or final year projects were sufficiently good for subsequent publication leveraged them to great effect to obtain competitive STEM jobs.
4. The anecdotal observations listed above need to be further confirmed with rigorous longitudinal studies

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