AC 2007-271: EXPLORING ACADEMIC FACTORS AFFECTING ENGINEERING GRADUATE STUDENT RESEARCH PROFICIENCY

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Exploring Academic Factors Affecting Engineering Graduate Student Research Proficiency

Abstract

It is paramount that engineering graduate students are proficient in research for research is the centerpiece of graduate-level engineering education. In order for graduate student research deficiencies to be resolved, factors affecting research proficiency for various types of graduate students must be understood. Unfortunately, graduate-level research deficiencies are cited sporadically in literature and are often studied using anecdotal data, so many deficiencies existing globally have not been resolved definitively. Despite the lack of documented findings, we discovered much about student research proficiency in our environmental engineering graduate program through sustained student assessment.

Academic preparation to perform research, organization in executing research, and research progress are general metrics we used to quantify research proficiency in two assessment studies. Analysis of more-specific variables indicated significant research deficiencies for a large number of students assessed. Variances in assessed proficiency were correlated to factors such as graduate degree program, length of graduate study tenure, academic background, and student-advisor communication.

Student motivations for study are tied to research proficiency. We assessed student perceptions of research success criteria that included learning achieved, professional development, progress toward graduation, and number of papers published; we learned that students overall value personal advancement/enrichment criteria over paper-publishing criteria that some faculty members consider to be very important metrics for research success. However, we found variances in perceptions of importance correlated to the demographic factors degree program and length of study tenure.

In our program, assessment studies isolated potential causes of and conditions associated with graduate student research deficiency. With collected data, students and faculty members in our program are seeking to provide better guidance for graduate students in research. Deficiencies we discovered are common on the global scale, but sustained student assessment shows promise in being the first step towards definitive solutions.

Introduction

Graduates of advanced-degree engineering programs are responsible for the future of engineering as expert industrial practitioners, researchers who develop innovative technologies, and academic instructors of future engineers. The importance of the engineering graduate degree is being recognized increasingly. For instance, the National Academy of Engineering report Engineer of 2020: Visions of Engineering in the New Century\(^1\) states that the typical engineering baccalaureate degree program cannot accommodate the academic development needed now for professional engineers and recommends that the master’s degree be considered the first professional engineering degree. Research is the centerpiece of graduate-level engineering
education for it is the means by which students can apply basic engineering knowledge to synthesize new ideas and make discoveries. The importance of research to engineering graduate study is validated by the ABET “General Criteria for Masters Level Programs”\textsuperscript{2} for the 2007-08 accreditation cycle stipulating that an engineering master’s degree graduate should satisfy baccalaureate curriculum criteria and demonstrate mastery of a particular subject and a high level of communication through completion of an engineering project or a research activity. (Common ABET baccalaureate curriculum criteria include proficiencies in performing statistics, conducting experiments, and critically analyzing data.) It is implied that an engineering doctoral degree graduate should satisfy the master’s-level criteria and demonstrate expertise in a subject through an advanced research activity. Considering the growing necessity of graduate-level engineering education and, subsequently, the research aspect of graduate engineering work, it is paramount for students pursuing engineering graduate degrees to be highly proficient in research.

Unfortunately, indicators of serious research deficiencies are documented in literature. The National Science Foundation studied graduation times of U.S. doctoral students\textsuperscript{3} and found that the median “total” time (i.e., time including periods when a student is not formally registered in graduate school) for a student to earn an engineering doctorate degree after completing undergraduate studies increased somewhat steadily from 7.6 years in 1978 to 8.6 years in 2003. In terms of “registered” time, the median graduation time was 5.8 years in 1978 and 6.9 years in 2003. This increase in time implies that impedance of student proficiency in graduate study may be occurring on a widespread basis. Also noted are communication deficiencies for students\textsuperscript{4}, especially international students\textsuperscript{5}, in U.S. graduate programs and the extracurricular measures taken to remedy these deficiencies due to insufficient measures in graduate-level curricula. It was found that a student belonging to an underrepresented demographic subgroup can experience obstacles in achieving graduate study goals or even in entering an engineering graduate program\textsuperscript{6}. Instances are recorded of strained student-advisor relationships that, in some cases, seem to be consequences of disparities in study motivations between students and faculty advisors\textsuperscript{7}. Research deficiencies apparently are not confined only to the U.S. Data suggests that many Ph.D. students in Portugal are not equipped academically for graduate work, lack formal guidance in performing research, and have mandatory responsibilities in conflict with their personal study goals\textsuperscript{8}.

Deficiencies like those cited above are documented sporadically in engineering education literature and are often studied primarily using anecdotal data. Thus, it is not surprising that definitive solutions have not been presented for many research deficiencies common globally. The first step in significantly improving graduate student research proficiency is improving the knowledge base regarding engineering graduate student experiences and motivations on the institutional and global levels. Current measures for gauging the quality of education in engineering graduate programs like the questionable \textit{U.S. News and World Report} rankings\textsuperscript{9} do not truly measure the development of students as researchers or the meaningful outcomes of that development. The demand for this first step is apparent in the proposed change to the ABET criteria for master’s-level programs which, if approved, would stipulate that such programs “must develop, publish, and periodically review educational objectives and program outcomes”\textsuperscript{2}.

In our environmental engineering graduate program, we took the first step in resolving our graduate student research proficiency issues earnestly. This paper details the findings regarding
research proficiency we discovered through sustained assessment of students in our program. Our work brought light to concerning trends in perceptions of research proficiency associated with our overall student population and with specific demographic subgroups. We also discovered much about the study goals of students in our program through perceptions of importance regarding research success criteria and the possible impacts those goals have on research proficiency. The deficiencies of our program are largely congruent with those documented in literature to date, so our findings concerning research proficiency are potentially applicable globally.

**Assessment in Our Program**

**Summary of Work Performed**

Since 2004, our program has conducted careful assessment of graduate student experiences and perceptions of academic conditions in the program, especially with regard to the quality of research performed by graduate students. The initial development of our assessment methods is detailed in the work of Rogers et al. 10.

As of the writing of this paper, two assessment studies have been performed in our program, and a third assessment study is being prepared. The 2004-05 study was discussed in broad terms in the work of Rogers et al. 10. That study yielded a high response of 50 students (greater than 75% of the student population at the time of the study), accurate representation of the overall population and demographic subgroups, accurate and salient data with respect to true student perceptions, and much positive student feedback. The survey for that study is provided in the work of Rogers et al. 10.

Continued assessment beyond the 2004-05 study was needed in order to provide:
- continued acknowledgement that research is the centerpiece of graduate-level engineering education,
- validation of the salient findings of the 2004-05 study,
- reassessment of variables associated validity or specificity concerns according to student feedback obtained during the 2004-05 study,
- characterization of potential variances in academic perceptions over time,
- handling of emerging academic concerns in our program, and
- a foundation for monitoring variables over a large period of time.

The 2005-06 study successfully met the above needs and provided promise for continuous, constructive assessment in our program. It mirrored the 2004-05 study in many ways but included some minor adjustments such as necessary changes in question mechanics and answer formats, addition of questions to address new concerns, removal of questions representing concerns that were resolved or assessed amply in the 2004-05 study, and reordering of questions from the 2004-05 survey on the 2005-06 survey so that responses would not be biased by the respondent’s recalling question patterns and answering behaviors from the 2004-05 study. The survey for the 2005-06 study can be obtained for referencing by contacting the primary author of this paper.
As in the case of the 2004-05 study, the 2005-06 study yielded a very viable response; 55 students (about 75% of the student population at the time of the study) completed and returned the survey. Again, the population overall and demographic subgroups were represented sufficiently. Many results of this study echoed the findings of the 2004-05 study, while others were interestingly different.

As a reference for interpreting the findings we present in sections below, five-point scale answer formats on the surveys of both studies are represented numerically with “1” representing the “absence” (e.g., not prepared) or “extreme negative” (e.g., very unsatisfied) end of the scale and “5” representing the “presence” (e.g., very well-prepared) or “extreme positive” (e.g., very satisfied) end of the scale. The symbol “SD” is shorthand for standard deviation, and “r” represents a correlation coefficient.

Program Demographics

As stated in the work of Rogers et al., the diversity of students in our program adds to common assessment obstacles, but the diversity provides opportunities for understanding specific demographic subgroups of our student population and addressing deficiencies in focused manners. Demographic categories that were associated with significant findings in our studies are:

- home country (only in the 2004-05 study),
- respondent’s first language (substituted for home country in the 2005-06 study due to respondent discomfort),
- undergraduate major,
- degree program, and
- year of graduate study tenure.

Figures 1 through 5 below give a breakdown of student respondents in our studies with respect to the significant demographic subgroups.

![Figure 1](image-url)  
**Figure 1.** Percentages of respondents per home country category for the 2004-05 study.
Figure 2. Percentages of respondents per first language category for the 2005-06 study.

Many students in our program are international students, and most of those students have languages other than English as their first languages. Figures 1 and 2 highlight the potential for communication difficulties that exists in our graduate student population.

Figure 3. Percentages of respondents per undergraduate major category for the 2004-05 and 2005-06 studies.

Environmental engineering, civil engineering, and chemical engineering make up the majority of undergraduate majors of students in our program as indicated in Figure 3. Thus, survey results for both studies were analyzed with respect to only the three primary majors in multivariate analyses where undergraduate major was an independent variable.
Ph.D. students make up about three-quarters of our research-oriented student population as shown in Figure 4. Thus, it was critical that we maximized the response of research-oriented master’s students in our studies so that these master’s students would be represented adequately. We used caution in drawing overarching conclusions about our entire population from univariate analyses considering the predominance of the Ph.D.-student subgroup.

Upon comparing the salient demographic data of the two studies, the most noteworthy demographic category is year-of-study. The predominance of second-year students in the 2004-05 study was replaced by the predominance of first-year students in the 2005-06 study as illustrated in Figure 5. The large subgroup of first-year students in the more-recent study causes more potential for bias in results since first-year respondents may have not had ample hindsight.
perspective at the time of the study to answer research-oriented questions in a truly informed manner. The large difference existing between the two studies in the study tenure aspect of demographic makeup further supports the need for sustained assessment in graduate programs in order to account for substantial changes occurring frequently in engineering graduate populations.

First-year and second-year student respondents were split roughly evenly between the master’s and Ph.D. programs in both studies, and most respondents that indicated their being in the third year of study or a later year also indicated their being in the Ph.D. program for both studies. Therefore, the concentration of first-year students in the master’s-student subgroup was greater than the concentration of first-year students in the Ph.D.-student subgroup for both studies. In turn, some analyses involving degree program as an independent variable may have been affected by bias, especially in the case of the 2005-06 study.

Sensitivity Concerns

For reasons described in the work of Rogers et al., sensitivity analyses were conducted on data from questions in the 2004-05 and 2005-06 studies that had the potential to be affected by student involvement in carrying out the studies. There were not many indicators of severe involvement bias in either study, so we consider the results representative of the population at-large for both studies.

Assessment Findings

Student Perceptions of Research Proficiency

Research proficiency is an abstract concept, making it a difficult quality to measure without calculated assessment. To make research proficiency tangible and quantifiable, we employed the following general metrics:

- academic preparation to perform research,
- organization in executing research, and
- research progress.

With these metrics in mind, we generated questions for our studies that allowed student respondents to gauge their research proficiency and allowed us to pinpoint specific factors that affect proficiency in our program.

Student assessments of overall research preparedness per year of study for the 2004-05 and 2005-06 studies are given in Figure 6. In both studies, it was observed that students overall were not prepared acceptably for research when starting their respective graduate research endeavors and did not improve in research preparedness during the first year of study, but significant improvement occurred for students in years after the first year despite some overlapping of confidence intervals in Figure 6. The perceived lack of preparedness improvement during the first year is further supported by paired t-tests performed in both studies indicating that individual student improvements in preparedness were not apparent during the first year.
Perceived preparedness before starting the program (i.e., initial preparedness) was correlated to degree program and undergraduate major for significant numbers of students. In the 2005-06 study, research-oriented master’s students overall assessed themselves as less prepared initially (mean = 2.22) than did Ph.D. students (mean = 3.03), even though a high amount of variance among those in the small master’s-student subgroup caused t-test inconclusiveness. We believe a significant number of Ph.D. students in our program performed research activities prior to starting Ph.D. work, leading to the higher Ph.D.-student initial preparedness rating. Of the three primary undergraduate major subgroups, respondents in the 2005-06 study who majored in civil engineering as undergraduates overall assessed themselves as less prepared (mean = 2.25) than did those who majored in environmental engineering (mean = 3.00) and chemical engineering (mean = 3.11). Some amount of variance was associated with each undergraduate major subgroup, but we believe this variance to be a result of preparedness attained by students through other activities outside of the undergraduate curriculum.

Therefore, it appears that students in our graduate program population on average feel they need general research orientation upon entering graduate school and do not receive such orientation immediately. It is especially troubling that master’s students and students who majored in civil engineering as undergraduates overall are even more deficient initially in research preparedness than are students in other subgroups. Considering that Ph.D. students in our program usually take the doctoral qualifying exam at one year-of-study and that master’s students aim to earn their degrees within two years, a lack of research orientation in the first year of study could impede student progress toward graduation.
Students overall in both the 2004-05 and 2005-06 studies assessed their initial preparedness in all of the research skills listed in the respective surveys as having room for improvement. Statistics is the consensus lowest-rated skill in terms of initial preparedness. Figure 7 provides the results for initial research-skill preparedness assessments. It is not surprising that initial overall research preparedness was rated lowly by students in the population at-large given the results displayed in Figure 7.

![Figure 7](image-url)

**Figure 7.** Initial skill preparedness assessments for students overall in the 2004-05 and 2005-06 studies.

Perceived benefits of graduate work to student development of research skills drew concern in both studies. Students overall rated poorly the benefit of graduate work to their statistical knowledge as illustrated by Figure 8. Positive correlation of assessed statistics benefit to assessed initial preparedness in statistics ($r = 0.32$) was found in the 2005-06 study. The amount of correlation for that study was somewhat weaker than that found in the 2004-05 study ($r = 0.51$), but correlation exists to noteworthy degrees for both studies. Thus, some students without initial statistical knowledge may not experience any substantial development of that knowledge in graduate study. Also, benefits to developing communication skills and to proficiency in conducting experiments were assessed by significant numbers of students in unfavorable manners. While improvements in overall research preparedness may occur in years of study beyond the first year, it seems that our program has many students who feel deficient in crucial research competencies even after multiple years of study.
In the 2005-06 study, we observed from conclusive $t$-tests that students who had first languages other than English were much less prepared on average with regard to the communication skills (“in writing” mean = 2.84, “orally” mean = 2.69) than were those whose first language was English (“in writing” mean = 3.86, “orally” mean = 3.81). There is some evidence, though, that non-native speakers benefited more from graduate work in terms of communication skills (means = 3.58 & 3.65) than did native speakers (means = 3.10 & 3.15). Benefit ratings with respect to communication are still somewhat concerning for both native and non-native speakers and are associated with high amounts of variance ($0.88 < \text{SD} < 1.25$).

Analyzing the data for initial skill preparedness with respect to degree program in the two studies yielded interesting results which are provided in Table 1. Variances associated with the preparedness ratings were extremely high in general as implied by SD values in the table. Thus, conclusive statistical differences between degree programs were difficult to establish, but breaking down the data into degree program categories was somewhat revealing. Master’s students overall believed themselves to be initially more prepared in communication skills in comparison to Ph.D. students. The greater concentration of non-native speakers in the Ph.D.-student subgroup (65.8%) relative to that of the master’s-student subgroup (45.5%) led in part to the higher assessed initial preparedness in communication for master’s students. In all other skills, Ph.D. students assessed themselves as substantially more initially prepared overall than did master’s students. The only major difference in the degree program initial preparedness results between the two studies was associated with statistics. Initial preparedness ratings in statistics were roughly equal for master’s and Ph.D. students in the 2004-05 study, but Ph.D. students indicated more initial preparedness in the 2005-06 study than did master’s students.
Table 1. Selected assessments of initial skill preparedness as indicated in the two studies categorized by degree program. (Abbreviations: “MS Res” = research-oriented master’s degree program, “Concl” = conclusion.)

<table>
<thead>
<tr>
<th>Skill</th>
<th>Concl</th>
<th>MS Res</th>
<th>PhD</th>
<th>Concl</th>
<th>MS Res</th>
<th>PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>statistics</td>
<td>INC</td>
<td>2.09</td>
<td>1.14</td>
<td>2.63</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>communicating in writing</td>
<td>IND</td>
<td>3.55</td>
<td>1.44</td>
<td>3.16</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>communicating orally</td>
<td>IND</td>
<td>3.45</td>
<td>1.51</td>
<td>3.05</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>analyzing &amp; interpreting data</td>
<td>INC</td>
<td>2.55</td>
<td>1.29</td>
<td>3.26</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>conducting experiments</td>
<td>INC</td>
<td>2.45</td>
<td>1.37</td>
<td>3.12</td>
<td>1.17</td>
<td></td>
</tr>
<tr>
<td>learning from literature you've read</td>
<td>INC</td>
<td>2.72</td>
<td>1.49</td>
<td>3.42</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>locating technical literature</td>
<td>IND</td>
<td>2.64</td>
<td>1.57</td>
<td>3.26</td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>

\( DIF \) – statistical difference indicated by \( t \)-test (\( p < 0.01 \))

\( INC \) – \( t \)-test results inconclusive (\( 0.01 \leq p \leq 0.10 \))

\( IND \) – statistical indifference indicated by \( t \)-test (\( p > 0.10 \))

Assessed skill benefit data were also analyzed with respect to degree program. Salient results of this analysis are given in Table 2. Large variances are associated with these results as well. Also, there were substantial increases in the mean ratings with respect to some of the skills for master’s students in the 2005-06 study relative to the mean ratings in the 2004-05 study. We are not certain what caused such a jump in the ratings, but we suspect biases associated with first-year students and the small size of the master’s-student subgroup as possible causes. For both the 2004-05 and 2005-06 studies, Ph.D. students assessed benefit to communicating in writing statistically more favorably than did master’s students. Deficiency in the development of written communication abilities for master’s students is especially concerning as many master’s students in our program continue onto Ph.D. programs or pursue careers in engineering research upon graduation.
Table 2. Selected assessed skill benefits as indicated in the 2004-05 and 2005-06 studies categorized by degree program.

<table>
<thead>
<tr>
<th>Skill</th>
<th>Program Benefit, 2005-06</th>
<th>Program Benefit, 2004-05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Concl</td>
<td>MS Res</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>communicating in writing</td>
<td>DIF</td>
<td>2.55</td>
</tr>
<tr>
<td>communicating orally</td>
<td>IND</td>
<td>3.27</td>
</tr>
<tr>
<td>critically analyzing information &amp; arguments</td>
<td>IND</td>
<td>3.73</td>
</tr>
<tr>
<td>analyzing &amp; interpreting data</td>
<td>IND</td>
<td>3.73</td>
</tr>
<tr>
<td>conducting experiments</td>
<td>IND</td>
<td>3.13</td>
</tr>
<tr>
<td>learning from literature you've read</td>
<td>IND</td>
<td>4.00</td>
</tr>
<tr>
<td>locating technical literature</td>
<td>IND</td>
<td>4.09</td>
</tr>
</tbody>
</table>

DIF ~ statistical difference indicated by t-test ($p < 0.01$)
INC ~ t-test results inconclusive ($0.01 \leq p \leq 0.10$)
IND ~ statistical indifference indicated by t-test ($p > 0.10$)

We learned from these analyses that development in skills such as statistics and communication is needed by the majority of our students, but development of research skills would be served well by tailoring development techniques according to the characteristics of specific demographic subgroups.

In addition to academic preparedness, organization and progress in research work are considered factors of research proficiency as stated previously. Findings regarding research organization and satisfaction in research progress as perceived by students in both studies are given in Table 3. On the whole, students were only slightly more than satisfied with respect to research progress, and they barely qualified their research as organized. It is interesting that the correlation coefficient for the relationship between progress and organization was much smaller for the 2005-06 study than it was for the 2004-05 study. The smaller coefficient in the 2005-06 study is likely due to the lack of precision associated with the five-point scale answer format. Thus, we believe that the positive correlation does exist to some noteworthy degree, but we are unable to characterize it further.
Table 3. Findings regarding research progress satisfaction and research organization assessments for the 2004-05 and 2005-06 studies.

<table>
<thead>
<tr>
<th>Variable / Analysis</th>
<th>Result, 2005-06</th>
<th>Result, 2004-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Research Progress Satisfaction</td>
<td>$95% \ CI = 3.47 \pm 0.21$</td>
<td>$95% \ CI = 3.63 \pm 0.24$</td>
</tr>
<tr>
<td>(b) Research Organization</td>
<td>$95% \ CI = 3.17 \pm 0.23$</td>
<td>$95% \ CI = 3.28 \pm 0.26$</td>
</tr>
<tr>
<td>Correlation of (a) to (b)</td>
<td>$r = 0.21$</td>
<td>$r = 0.55$</td>
</tr>
</tbody>
</table>

We also explored the possible relationship of research organization with the respondent’s degree program. Some statistical evidence that Ph.D. students were more organized (mean = 3.43) as a whole than were master’s students (mean = 2.83) surfaced in the 2004-05 study, but we found in the 2005-06 study that master’s students (mean = 3.11) and Ph.D. students (mean = 3.21) were much more indifferent in their assessments of research organization. In any case, organization seems deficient for both degree program subgroups. Also, research organization was significantly positively correlated to student-advisor communication in both studies (2004-05 $r = 0.40$; 2005-06 $r = 0.37$), so dysfunctional communication between student and advisor may negatively affect the student’s research organization and, in turn, research proficiency.

Student Perceptions of Research Success Criteria Importance

The understanding of student motivations for study is crucial to diagnosing the root causes for research deficiency. If a student is not putting enough emphasis on proper study goals or if the goals of a student and a faculty advisor are in conflict, the student’s level of research proficiency may suffer. For instance, a particular student may only care about doing the necessary work to obtain a graduate degree while the student’s advisor may consider only journal paper production as the metric for research success. The attitudes of this student and this advisor may lead to a strained student-advisor relationship, prolonged study times resulting from miscommunication of goals, and unsatisfactory student research outcomes. In order for students to get the most out of graduate education, proper goals and expected outcomes of study need to be unambiguous and in the best interests of both student and advisor. It would be more effective in the hypothetical case if student and advisor were to have better dialogue so that student and advisor could adjust individual goals in order to serve mutual goals. We detail below salient findings regarding perceptions of importance students in our program had about specific research success criteria while exploring disparities that exist between students and faculty members and determining demographic factors that help shape student motivations.

Figure 9 provides importance assessments of the five criteria common to both the 2004-05 and 2005-06 studies for comparison. There is a very significant statistical difference seen between the ratings of advisor approval in the two studies; potential reasons for such a difference include biases resulting from the large amount of first-year students in the 2005-06 study or from different orders of questions with respect to the two surveys. We suspect the latter of the two possible reasons. The ratings for this criterion further highlight the need for continued assessment so that factors creating sensitivity in answering behaviors can be isolated over time. Other criteria do not statistically differ in rating with respect to the two studies. It is also noted that the publishing-related criteria experienced relatively large variances in importance rating, while learning achieved and progress toward thesis/project completion achieved better consensus in rating among students.
We are confident that research criteria of most importance to students in our program in the broad sense are ones involving personal academic enrichment or advancement such as learning achieved and progress in graduate work. Though there were some amounts of variance in the importance ratings of publishing-related criteria, the results of the two studies indicate lesser importance associated with publishing-related criteria in relation to achievement/enrichment criteria.

Respondents in the 2004-05 study provided research success criteria they believed were important in addition to those listed on the survey. Three of the more-popular additional criteria were personal satisfaction, professional development, and practical application of research. Thus, we assessed student perceptions of these criteria quantitatively in the 2005-06 study. Table 4 gives the overall student assessments of importance of these additional criteria.

Table 4. Importance ratings of research criteria unique to the 2005-06 study.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Importance (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>personal satisfaction</td>
<td>4.47 ± 0.21</td>
</tr>
<tr>
<td>professional development</td>
<td>4.32 ± 0.23</td>
</tr>
<tr>
<td>practical application of research</td>
<td>3.76 ± 0.26</td>
</tr>
</tbody>
</table>

It seems that the personal satisfaction in performing research and the professional development occurring in the research process are very important to students overall in our program. These results further support the perceived general importance that students associate with personal advancement and enrichment. In contrast, there was some diversity in the perceptions of students regarding the practical application of research. We observed that practical application
was significantly negatively correlated to the respondent’s year-of-study \((r = -0.57)\), implying that the perception of importance of practical application may decrease as the respondent’s year-of-study increases for some significant number of respondents. We believe that the higher assessed importance of practical application indicated by students of shorter tenure may be due to an appreciation of “real-world” relevance of work over academic relevance felt by some students early in tenure which may shift to an appreciation of academic relevance later in tenure. It would be potentially concerning if some students lack appreciation for the academic relevance earlier in tenure or for the real-world relevance later in tenure as research outcomes can affect both the real world and the academic world.

Concerns of disparity between the goals of our students and those of faculty members were supported by the comments of several faculty members obtained from informal interviews that took place after the 2004-05 study. Those faculty members placed much weight on journal paper publication as a key criterion for research success. It was also suggested by students in a follow-up discussion group during the 2005-06 study that publishing papers was very important to faculty members in our program.

We examined the data in Table 5 in order to characterize how perceptions of research success criteria varied by degree program in both studies.

**Table 5.** Importance ratings of research criteria categorized by study and degree program.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Importance, 2005-06</th>
<th>Importance, 2004-05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MS Res</td>
<td>PhD</td>
</tr>
<tr>
<td>advisor approval</td>
<td>IND</td>
<td>4.70</td>
</tr>
<tr>
<td>learning achieved</td>
<td>IND</td>
<td>4.60</td>
</tr>
<tr>
<td>progress toward thesis/project completion</td>
<td>IND</td>
<td>4.50</td>
</tr>
<tr>
<td>personal satisfaction</td>
<td>IND</td>
<td>4.50</td>
</tr>
<tr>
<td>professional development</td>
<td>IND</td>
<td>4.20</td>
</tr>
<tr>
<td>number of papers published</td>
<td>INC</td>
<td>2.90</td>
</tr>
<tr>
<td>particular journals where your papers are published</td>
<td>IND</td>
<td>3.56</td>
</tr>
<tr>
<td>practical application of research</td>
<td>DIF</td>
<td>4.40</td>
</tr>
</tbody>
</table>

*DIF* ~ statistical difference indicated by t-test \((p < 0.01)\)

*INC* ~ t-test results inconclusive \((0.01 \leq p \leq 0.10)\)

*IND* ~ statistical indifference indicated by t-test \((p > 0.10)\)

We made several key observations based upon the data in Table 5. Even though high variances and the limited number of master’s-student respondents made the disparity of publishing
importance between master’s and Ph.D. students less clear in the 2005-06 study than the
disparity was in the 2004-05 study, there was a stronger consensus among Ph.D. students versus
master’s students in general on the importance of publishing papers as demonstrated by the mean
values in Table 5. The difference in the assessment of advisor approval importance between the
two studies illustrated in Figure 9 is not correlated to degree program. Also, master’s students
overall put much more importance weight on practical application than did Ph.D. students. We
believe many master’s students assessed practical application highly because their ultimate
career goals may have consisted of industry, consulting work, or other non-academia endeavors.
Though most master’s students in both studies were of two years of study tenure or less,
master’s-student responses did not greatly affect the negative correlation of practical application
importance to respondent year-of-study in the 2005-06 study described above.

Thus, in addition to possible disparities between students and faculty members in our program
regarding study goals, goal disparities exist among the different student demographic subgroups.
Of course, goals vary much on the individual student level as well. The diversity of student
goals we found in our studies highlights the need for meaningful communication to take place
among students and between students and faculty members in an engineering graduate program
in order for a particular student researcher to be initially guided onto the most-proficient path of
study.

Concluding Remarks

We demonstrated through our studies that sustained assessment of engineering graduate students
can sufficiently provide specific measurements of graduate student research proficiency and
isolate the particular factors affecting proficiency. Students and faculty members in our program
are beginning to seek tangible improvements based on study data in preparing students for
research and in guiding students to carry out research. We are investigating feasible ways to
better education for all students in our program with respect to statistics and communication.
Even more-abstract skills like time management are being emphasized in efforts to help students
become more organized in carrying out research. Special attention is being given to first-year
students, master’s students, non-native speakers, and students with civil engineering
backgrounds as these demographic subgroups are associated with much concern. In addition, we
now have a starting point to establish a dialogue about study goals among students and between
students and faculty members in order to create clear visions for desired outcomes of student
research. With continued assessment, we will be able to monitor student study motivations and
the related measures of research proficiency for years to come.

Engineering graduate programs worldwide are likely experiencing student research deficiencies
similar to those discovered in our program. Therefore, potential exists for further exploration of
proficiency issues through student assessment. With awareness of graduate student experiences
and motivations, the global engineering academic community can begin searching earnestly for
definitive solutions to improve research proficiency for the pivotal engineers of the future.
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Bibliography