Introducing Diverse Undergraduates to Computational Research

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Introducing Diverse Undergraduates to Computational Research

This paper discusses the importance of a heightened emphasis on African-American undergraduate engineering students. The paper also reports on a three-year project that recruited diverse undergraduates to a ten-week research experience with a focus on computational modeling and research. As the data reported will reveal the students represent different disciplines, different institution sizes, were ethnically diverse and had a balance of female and male students. The faculty mentors of the students’ research were from different academic disciplines within engineering. The research projects had goals that were different while employing similar research tools. Such a multi-dimensional diversity was made possible by the recruitment goals set by the project team, and by the inherent nature of computational modeling.

1.0 importance of undergraduate research for diverse students:

Table 1 presents data from American Society of Engineering Education’s annual report on engineering education data for 2018 from U.S. institutions. Tables 1(a) - (d) present the 10-year trend of B.S., M.S. and Ph.D. graduates, and tenured and tenured faculty. There have been several initiatives, both sponsored and unsponsored, that have had the goal of addressing diversity and inclusion in various facets of engineering education. The data in these tables for the two largest underrepresented groups: African-Americans and Hispanics is revealing. As a percentage, the range of degrees awarded in engineering at the B.S., M.S., and Ph.D. levels has been 3.5 - 4.6, 4.4 - 5.1, and 3.2 - 4.4 respectively for African-Americans. During the same period, as a percentage, the range of degrees awarded in engineering to Hispanics at the B.S., M.S., and Ph.D. levels has been 6.6 - 11.4, 5.3 - 8.8, and 3.8 - 6.3 respectively. Further, looking at the sequence of numbers, it is clear that at all three levels the percentage of degrees awarded to African-Americans has remained at the same level over this decade; at all three levels the percentage of degrees awarded to Hispanics has shown a significant upward trend. The percentage of tenured and tenure-track faculty over this decade has remained at about the same percentage over this decade.

Table 1. Data from US Engineering Programs 2009-2018 [1]
(a) Engineering BS degrees awarded in U.S. during 2009 - 2018

<table>
<thead>
<tr>
<th>BS degrees awarded %</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black or Afr. American</td>
<td>4.6</td>
<td>4.5</td>
<td>4.2</td>
<td>4.2</td>
<td>4.3</td>
<td>3.5</td>
<td>4.0</td>
<td>3.9</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Hispanics</td>
<td>6.6</td>
<td>7.0</td>
<td>8.5</td>
<td>9.0</td>
<td>9.3</td>
<td>10.1</td>
<td>10.7</td>
<td>10.7</td>
<td>11.1</td>
<td>11.4</td>
</tr>
<tr>
<td>Other</td>
<td>11.0</td>
<td>1.2</td>
<td>1.6</td>
<td>2.0</td>
<td>2.3</td>
<td>2.9</td>
<td>3.1</td>
<td>3.6</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td>White</td>
<td>65.4</td>
<td>69.8</td>
<td>66.6</td>
<td>66.2</td>
<td>65.7</td>
<td>65.9</td>
<td>64.9</td>
<td>63.4</td>
<td>62.3</td>
<td>61.5</td>
</tr>
<tr>
<td>Unknown</td>
<td>5.3</td>
<td>6.9</td>
<td>6.5</td>
<td>5.6</td>
<td>4.5</td>
<td>3.9</td>
<td>4.2</td>
<td>4.1</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>
An important factor in motivating undergraduates to consider and pursue M.S. and Ph.D. degrees is for them to participate in research experiences as an undergraduate. Yoon, et al [2] report on the impact of two summer research experiences for undergraduates (REU) programs on diverse students from the USA and India. A large number of students came to favor graduate education and research after their summer research experience. Importantly, the students also noted that the skills they acquired at the REU would not have been possible at their home institutions. Rosetti, et al [3] report on a program at University of Arkansas that motivates students to complete a research-based M.S. degree along with their B.S. in engineering while providing an opportunity to a cooperative education with a corporate research sponsor.

The decade of data on engineering students and faculty in Table 1 indicate the dire need for growth in these areas. Research experiences such as REUs for African-American undergraduates can contribute to a positive upward trend in M.S. and Ph.D. degrees for this group in the future; this in turn can positively impact the percentage of tenured and tenure-track African-American faculty in engineering.

**2.0 engineering modeling and computational research**
The College of Engineering at North Carolina A&T State University (NCAT) comprises seven academic units. Research in these units includes both experimental and modeling and computational work. The experimental work is housed in several laboratories and a few centers. Research with a modeling and computational emphasis is conducted in single or small faculty group research laboratories, and in some instances, the high performance computing facilities in the College. In 2010, the Computational Science and Engineering (CSE) department was established. CSE has graduate programs at the MS and PhD levels (but no undergraduate program) and houses the primary high performance computing facilities in the college. Using the foundation offered by the small faculty group’s research laboratories and the CSE program, we implemented a Research Experiences for Undergraduates (REU) program entitled Engineering Modeling and Computational Research at NCAT (EMCoR@NCAT). This REU hosted three student cohorts in 2016, 2017, and 2018.

The REU experience occurred within a 10-week residency period during the summer. Participants spent 36 hours per week on research and related instruction, and roughly 4 hours each week on outreach and team-building activities. Each participant underwent a four-step process to complete the REU program: 1) pre-program preparation, 2) on-site focused modeling and computation instruction, 3) research integrated with professional development and outreach, and, 4) project delivery and dissemination. Students’ progress towards stated goals was assessed during this process to enable improvement throughout the life of the REU program. By the end of the research experience, the goal was that participants in the REU would be able to:

(a) **demonstrate** an understanding of the tools available for modeling and computational research;
(b) **state and communicate** a research problem and research goals in a domain, with the guidance of a research mentor;
(c) **plan and complete** a research task with the guidance of a research mentor;
(d) **demonstrate** intellectual independence and creativity; and
(e) **communicate** the research problem, goals, plan, work, and results to diverse audiences.

Recruitment efforts were to target rising juniors and seniors who have strong mathematics and physics backgrounds. Some exposure to engineering coursework was desirable, but not required. Aptitude towards computational work evidenced by applicants’ transcripts was to also be considered. A special focus was to recruit students enrolled in institutions, from the region that includes North Carolina and the neighboring states that may not have the resources to offer research experiences in these fields.

The initial set of project topics planned included: Shock Motion in Supersonic Vehicles, Hydrologic Simulation, Computational Biomechanics, Humanitarian Logistics, Analysis of Soft Gels, Energy Efficiency of Buildings, and Nondestructive Testing. After the participants completed a week-long introductory course, they were to transition to the research-intensive portion of the REU. Each participant was to meet with their mentor to finalize their respective research project plans. Plans were to be presented to the faculty mentor and research group in a seminar format on the first Friday of the second week. The participants were to spend the majority of the next seven weeks completing research activities with the faculty mentor. Participants were required to participate in three individual meetings with mentors each week, one weekly research group meeting, and have daily interactions with graduate research assistants. All mentors emphasized positive interdependence within their research group, face-to-
face interactions, individual accountability, skills for functioning in groups, professional skills as it relates to research, and collective discussion of the research of all students in the group. The introductory course instructors were available to assist via email or by appointment. Professional development workshops, industry visits, and volunteer outreach activities were also planned. The research experience ended with submission of individual research reports and presentations to faculty, graduate students, and fellow participants.

3.0 outcomes of the REU

The following sub-sections summarize the outcomes of the REU over the three-year period.

3.1 student participants
The application count for the first, second, and third year were 44, 55, and 76 respectively. Our recruitment strategy included targeting a diverse group of students from institutions that did not offer graduate degrees in engineering. As a part of this strategy, we collaborated with the Virginia – North Carolina Alliance for Minority Participation to recruit participants from its partner schools that met our criteria, as well as through the national portal. Diversity for our three cohorts included race, gender, institution type (i.e. HBCU, PWI, private, public, etc.), and major.

Cohort 1 consisted of four females and six males, of which seven of were African-American, one Caucasian, one African, and one Asian. Institutional profiles consisted of three HBCUs (1 public land grant, 2 private), three PWIs (1 private, 1 land grant, and 1 public), and one community college. Due to the interdisciplinary nature of the program, student came from seven majors: bioengineering, information technology, chemical engineering, electrical engineering, mechanical engineering, computer engineering, and mathematics.

Based on evaluation feedback and lessons learned during the recruitment of our first cohort, recruitment of Cohort 2 participants began earlier in the academic year, commencing in January 2017. The diversity of this cohort was slightly less than the previous year; however, more disciplines were represented: four computer science majors (one double majoring in mathematics, and one minoring in Business Administration), one computer engineering major, four biomedical/bioengineering majors, one environmental science, and one mathematics major (minoring in computer science). Institutional profiles included four HBCUs (2 public, 2 private), and two PWIs (1 land grant, 1 private). In terms of gender and race, participants included four females and six males. Seven were African-American, two Caucasian, and one was Asian.

Ethnic and gender distributions for Cohort 3 were roughly even. As in years 1 and 2 of the project, a cohort of 10 students were selected; however, through a collaboration with a DHS summer REU on campus, two additional students were added, yielding a total of 12 students for this cohort. Six were male and six were female. Seven were African-American, and five were Caucasian representing nine institutions. Institutional profiles included four public HBCU, one PWI land-grant institution, and one private PWI. Disciplines represented were three computer science majors, two computer engineering majors, two applied mathematics/engineering math majors, two mechanical engineering majors, one kinesiology major, and one information technology major.
Table 2 shows the distribution of the students by classification, major, gender, and race; the classification of the students ranged from freshman to seniors, and they came from nine different majors. Across the three cohorts, males and females had a balanced representation, and three major race classifications were represented. Table 3 characterizes the size of the students’ home university and the highest degree offered; the home universities varied in the size and highest degree metrics. Tables 2 and 3 also show a rich diversity among the 32 students. The program served nine students who were not from computer science and engineering; the REU experience has the potential to make a significant change in the career aspirations of these students.

Table 2. Student classification & major for 2016-18 cohorts

(a) Student Classification

<table>
<thead>
<tr>
<th>Class</th>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
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<tr>
<td>2016</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>2017</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2018</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>12</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

(b) Student Major

<table>
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<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
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<tr>
<td>2017</td>
<td>4</td>
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<td>2</td>
<td>3</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>2018</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
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<td>2</td>
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<td>Total</td>
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<td>1</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
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</table>

(c) Student Gender and Race

<table>
<thead>
<tr>
<th>Gender</th>
<th>Race</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
</tr>
<tr>
<td>2016</td>
<td>6</td>
</tr>
<tr>
<td>2017</td>
<td>6</td>
</tr>
<tr>
<td>2018</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>18</td>
</tr>
</tbody>
</table>

Table 3. Student home university enrollment & terminal degree in science & engineering

(a) Enrollment

<table>
<thead>
<tr>
<th>Enrollment</th>
<th>&lt; 2000</th>
<th>2000 - 4999</th>
<th>5000 - 9999</th>
<th>10000 - 14999</th>
<th>15000 or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td></td>
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<tr>
<td>2017</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>6</td>
</tr>
</tbody>
</table>

(b) Terminal degree

<table>
<thead>
<tr>
<th>Terminal degree</th>
<th>AS</th>
<th>BS</th>
<th>MS</th>
<th>PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2017</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
<td>13</td>
<td>6</td>
<td>12</td>
</tr>
</tbody>
</table>
3.2 faculty mentors and introductory course instructors
The instructors for the introductory course were faculty members from Computational Science & Engineering, Chemical Engineering, and Industrial & Systems Engineering. The research mentors were from Bioengineering, Civil Engineering, Computational Science & Engineering, Industrial & Systems Engineering, and Mechanical Engineering.

3.3 research projects
The titles of research projects for the 2016 cohort are listed below to present the diverse problem domains; the last two topics in this list are from the 2018 cohort.

- Numerical Modeling of Soft Polymers
- Modeling Donor Behavior in donations to Non-Profit Food Organizations
- Advances in Thermographic Signal Reconstruction for Infrared Thermography Non-Destructive Testing
- Modeling of Shock Motion in Supersonic Vehicles
- Forecasting Savings of Building Energy Systems using Artificial Neural Networks
- Finite Element Analysis of Magnesium ACL Interference Screw resilience of the screw in resisting movement in the bone
- Hydrological Modeling: Application of HEC-HMS
- Prediction of energy consumption in buildings by system identification
- Analysis of Defect Detection in CFRP Aircrafts Using Thermographic Nondestructive Evaluation
- Finite Element Analysis of Anterior Cruciate Ligament (ACL) Screw Fixation Using Polyurethane Foam
- Sentiment Analysis on Interdependent Social Networks
- Star-Based Centrality Metrics for Critical Node Detection in Interdependent Networks

3.4 student publications
The following publications by the student participants. The publications were directly based on the research paper prepared by the end of the REU program, and listed the student as the first author in each case.


3.5 professional development and outreach

The following professional development activities (one hour each) were arranged for each cohort:

• Workshop by reference librarian on EndNote;
• Workshop on applying to graduate schools and preparing for the GRE;
• Workshop on applying for graduate scholarships and fellowships;
• Workshop on writing a research abstract; and,
• A talk on the discipline of Computational Science & Engineering.

Each cohort was taken on field trips to institutions or corporations such as SAS, Inc., the Research Triangle Institute (RTI), and RENCI (Renaissance Computing Institute), all in the RTP area of North Carolina. A blog article on this trip can be found at: http://renci.org/blog/nsf-funded-undergrad-researchers-get-a-taste-of-life-at-renci/. Students also had the opportunity to hear a two hour talk via video from Dr. Eric Brown, a pioneer in Computing Technology from IBM Research. As a part of our outreach, the students toured the Greensboro Civil Rights Museum and volunteered at a nearby farm that serves mentally and physically challenged individuals.

3.6 program assessment results

According to the internal and external evaluators for the project, overall, the EMCoR@NCAT REU Site was successful in meeting most goals in the 3-year period based on the results of the assessment. It is most important to note that this REU Site, run at an HBCU, met and exceeded
the diversity of most REU programs across the nation. In terms of broadening participation in engineering, note that the majority of the participants were African-American, while a significant number were non-African American. The last cohort showed more gender and ethnic diversity, with ethnic diversity reflecting just as many African-American participants as non-African American participants; gender percentages were also equal by the final year of the program.

**evaluation methodology**

The evaluation plan included a hypothesis of increased modeling self-efficacy from pre-test to post-test. Yildirim et al. [4] developed an Engineering Modeling Self-Efficacy (EMSE) instrument with 36 items and 7 dimensions drawn from Tsang’s (1991) stages of modeling. Five of the seven dimensions were selected for this project. The number of questions/items mapped to each dimension is shown in parentheses:

- Model review and evaluation (2)
- Conceptual design of a model (6)
- Modeling parameters (2)
- Understand results and evaluation (7)
- Validating a model (4)

The EMSE was administered on the first week of the REU and the final day of the REU for each cohort. Variables were created by mapping items to each dimension of the EMSE. A Cronbach’s alpha test of internal consistency was used to test the reliability of items on each dimension. All results are reported as coefficient $r_{alpha}$ values. Nunnally’s criterion of .70. However, some flexibility was used to ensure all five dimensions could be included in the analyses.

A paired t-test (dependent groups) was conducted to test the hypothesis of increased modeling self-efficacy from pre-test to post-test using an alpha criterion of .05. One dimension approached significance and one was significant at alpha = .05: *understand results and evaluation* [$t(9) = -2.20, p = .05$] and *validating a model* [$t(8) = -3.30, p < .05$]. Participants increased perceptions of modeling self-efficacy from pre-test to post-test on these two dimensions. Figure 3 illustrates changes for all dimensions. While only three dimensions achieved significance, all means trended in the expected direction. A validity check on gender was conducted to differential validity.

The Student Experiences Scale (SES) was used to assess students’ perceptions of the REU at the end of the summer. The evaluation plan set a criterion of 70% of students rating each item as “very good” or “excellent.” The SES was tested as a unidimensional scale using Cronbach’s alpha reliability. The $r_{alpha}$ value was .78. A frequency analysis was conducted to determine which items did not achieve the 70% criterion. Constructs (items) not meeting the criterion of 70% answering “very good” or “excellent” are listed below.

- The opportunity to learn more about modeling and computational skills and techniques (40%)
- The opportunity to learn more about the publishing process (50%)
- The opportunity to co-author and publish a scientific paper (60%)
- The development of skills in writing research results (20%)
- The development of skills in making scientific presentations (44%)
- The understanding of the practical application of your research (44%)
• The opportunity to engage in meaningful ways with the surrounding community (66%)
• The extent to which I can clearly discuss research with different groups of people (44%)

Additional analyses were conducted by dividing the SES into three dimensions, which included faculty engagement, academic growth, and professional skills development. The mean ratings on each dimension were compared to the maximum possible values on that dimension to compare student perceptions to the aspirational rating (maximum). The SES also contained open-ended responses allowing students to provide feedback. Open coding was used to extract themes based on the responses provided. Each utterance was counted as a data point, thus utterances may be higher than the number of participants.

Just-in-Time (JIT) focus groups were conducted at three points during the summer months. These focus groups were conducted to make adjustments quickly. The evaluation plan used a 40% criterion of increased positive themes from the beginning to the end of the summer. It was difficult to assess this criterion because students’ utterances in focus groups were difficult to count. A recorded session and a written transcript (as opposed to handwritten notes) would have improved the criterion determination. Data were provided to the site leaders after each focus group. Students’ positive and negative comments changed throughout the summer, but the themes remained concentrated in five specific areas: Mentoring, Structure/Organization of the Program, Socials, Residence/Dining Halls, and Technology (software, hardware, computer labs).

The project met its stated goals as follows:
• A core group of 6-8 faculty in engineering modeling and computational research participated in the REU.
• Professional preparation for participants included MatLab and Python training which the students found to be very important, and wanted more. Cohorts 2 and 3 reported strong positive statements around the availability of resources, computing spaces, and computer support. This was an improvement based on feedback from year 1 (cohort 1). The goal was exceeded in terms of professional skills development reported by women students in cohort 3 (2018). Students’ qualitative feedback in cohorts 2 and 3 indicated strong positive experiences around the social events and interacting with each other. Students in cohort 3 expressed positive statements around the diversity of the participants in the REU.
• Mentorship and guidance for research and professional preparation for graduate level studies.
• Objectives for student learning were met overall.

3.7 progression of the student participants post-reu
Of the 32 students who participated in the EMCoR REU at NCA&T, seven are employed, 16 are continuing their undergraduate education, and four are enrolled in graduate school. No additional information was provided for five students.

Table 4. The current status of the participants
(a) 2016 Cohort
4.0 conclusions:

The following key points summarize the contributions of this research. The discussions in sections 1, 2, and 3, lead to the following two conclusions:

1. The data and discussion in Section 1, provides a compelling argument to provide more opportunities for under-represented minorities, especially African-American students in engineering, to pursue M.S. and Ph.D. degrees. The literature bears testimony to the fact that undergraduate research can prepare and motivate students for graduate education. While such research experiences are widely available in large research-intensive campuses, they must be widely offered in small universities with a significant number of under-represented minorities. This will enable the research mentors in small universities, offer more motivated undergraduates a glimpse into research.

2. Undergraduate research in themes anchored in computational modeling, have several advantages in serving diverse students: (a) faculty with different research interests but using similar computational tools can team up to set up an undergraduate-focused research program; (b) different engineering majors and non-engineering majors with some preparation in math and computing can consider such a research experience; and (c) the research skills acquired by the students are largely transferable to several domains that the students may wish to pursue graduate research.

The following two conclusions are based on the experiences of the authors in developing and delivering the summer undergraduate research experience described in this paper. There is no elaboration of these two points in the rest of the paper, but are offered as observations to faculty researchers who may plan to offer a summer undergraduate research program.
1. Summer undergraduate research experiences have the advantage of making it possible for the participants to give focused attention to research, in contrast to pursuing research experience during the academic semesters. However, such programs are very intensive in the administrative effort required: housing, dining, outreach, and office / laboratory and meeting spaces. Another key issue is to ensure adequate participation of faculty and graduate student mentors for a long contiguous window of time (often 8 to 10 weeks); note that summer is also a time when faculty and graduate students may have other demands on their time that may take them away from campus.

2. The two challenges stated in #1 above, administrative effort and faculty / graduate student availability, are less of a problem for large research-intensive universities; this is usually because of the staff that may be available dedicated for such administrative work, and the faculty and graduate students being more likely to have financial support in summer via other projects. Federal sponsorship guidelines for summer undergraduate research experience adequately address support for student participants, but are very constrained in support for the administrative effort, and faculty and student support; this is clearly a challenge that small universities serving large number of underrepresented minorities face.

**References:**


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