AC 2008-2616: ENGINEERING EDUCATION IN BIOMIMETIC MICROELECTRONIC SYSTEMS: AN URBAN ENGINEERING RESEARCH CENTER'S RESPONSE

Gisele Ragusa, University of Southern California
Associate Professor Rossier School of Education

Michael Khoo, University of Southern California

Ellis Meng, University of Southern California

Engineering Education in Biomimetic MicroElectronic Systems: An Urban Engineering Research Center's Response

Abstract

In 2003, the National Science Foundation awarded a large private urban research university funds to create an Engineering Research Center (ERC)- a center dedicated to the coordination of groundbreaking research in the development of biomimetic devices. The ERC brings physicians, biologists, engineers and educators together to develop microelectronic systems that interact with living, human tissues. The resulting technology enables implantable and portable devices that can treat presently incurable diseases such as blindness, loss of neuromuscular control, paralysis, and the loss of cognitive function. The researchers focus on mixed signal systems on chip, power and data management, intelligent analog circuits, interface technology at the nano- and micro-scales to integrate microelectronic systems with neurons, and new materials designed to prevent rejection. The ERC has a significantly reformed engineering education effort with foci on undergraduate and graduate engineering with a BME application focus. These reform efforts combine the collaborative expertise of the university's school of engineering, a school of medicine and a school of education. The engineering educational reform efforts combine undergraduate and graduate coursework with comprehensive, innovative, and multidisciplinary laboratory experiences aligned to the ERC's BME test beds for all students. Students have opportunities to engage in powerful research side-by-side premiere researchers using an inductively based, situated approach to curriculum and instruction. The ERC's engineering educational approaches address four broad themes: *Access, Inductively based Situated Learning, Retention and Career* outcomes. This paper reports both on baseline access, retention, and career data and a logic model associated with a comprehensive curricular reform resulting from the access, retention and career baseline data. As a result of this baseline data, the ERC educational team has found innovative ways to infuse inductively based, situated curriculum and instruction in addition to a student-centric outcome metrics into all aspects of the BME curriculum and associated laboratory experiences. These assessment measures build on the principles established in educational psychology and include pre and posttest BME concept inventories, rubric-based laboratory assessments, BME efficacy measures and employer satisfaction measures. A comprehensive assessment profile is in the process of being created for program graduates at both the graduate and undergraduate levels. This ASEE paper is a "work in progress" report as the engineering education reform engaged in via the ERC represents a comprehensive reform process incorporated in to NSF engineering research center funding that extends for a ten year period.

Introduction and Overview

We live in an era with unprecedented changes due to dramatic advances in technology on many fronts. The explosive growth in computing and communication has revolutionized the way we work and live. Increasingly, the engineering work force is becoming more diverse with teams working with global foci. These forces of globalization, demographics, and technological advances are changing the role of engineering in society[1] calling for changes in the way universities address the engineering profession and education.

There have been many national level studies about critical issues facing the nation about the crisis in engineering education.[1] With outsourcing and offshore presence of engineering jobs, there is a growing concern about the level of interest among students choosing engineering field. While the number of engineering graduates per year has remained steady at about 70,000 in the United States, in the past decade the number of engineering graduates per year from China and India has grown at a significant rate. With the world becoming “flat” due to globalization, increasingly, jobs requiring basic technical skills are moving outside of the U.S. by companies to reduce cost. Engineering graduates from the U.S. must bring added value and higher-level skills including innovation, a problem solving approach, and leadership to garner higher salary jobs in U.S. companies. The call from various technical reports on engineering education is for U.S. higher education institutions to produce this kind of engineer. Accordingly, there is an urgent need for reforming and enhancing engineering curriculum to address these needs. This NSF funded BME focused urban ERC intends to meet these globally focused education needs through its educational efforts in curricular reform at both the graduate and undergraduate levels. In this paper, the ERC researcher report on preliminary data that have been collected to guide the curricular reform in addition to reporting on the comprehensive plan that they have developed to meet the needs of engineers in biomedical fields in 2020.[2]

Curricular reform is typically a slow and arduous process in research universities. Traditional curriculum in engineering education involves deductive instruction in which the instructors lecture on general principles with limited application of the principles to real life engineering situations and simulations. Deductive instructional approaches have significant limits in preparing engineers for a changing global society as required by the National Academy of Engineering. [2] The serious nature of the necessity for engineering education reform requires radically new and innovative curricular and assessment approaches. Such approaches must focus on inductive teaching and situated learning. Inductive approaches with situated learning opportunities include: inquiry focused learning, problem-based learning, vignette instruction and case-based instruction. [3] At the urban university where this ERC resides, the researchers/faculty have recently formed a Division of Engineering Education to develop and implement new curricular approaches for preparing our engineers for the global scene of 21st century work force utilizing inductive, situated approaches. The primary objective of the ERC connected engineering education research is to enhance engineering education on a continuous basis by applying well established learner-centered, inductive, situated instructional and assessment techniques that have been grounded in educational psychology and cognitive science principles to biomedical engineering curricula.

Existing Evidence From Relevant Prior Research:

The National Academy of Engineering (NAE) has alerted the nation that the engineering profession and engineering education must adapt to the changes in technology and society for the U.S. to strengthen its workforce and face growing challenges of globalization. [2] NAE quotes the National Science Board as stating, “The organizational structures for educating, maintaining skills, and employing science and engineering talent in the workforce are diverse and their interrelationships complex and dynamic. Accordingly, production and employment of scientists and engineers are not well understood as a system.” [4] NAE posits, “Although progress is being made in engineering education, much remains to be done in developing research base underlying best practices in engineering education [5] and faculty practice generally." [6] Upon completing a baseline needs assessment and "state of engineering education" environmental scan, the researchers/ faculty at the BMES ERC have chosen to engage in comprehensive engineering education reform on all education components associated with our urban ERC. These curricular reform efforts incorporate these recommendations through significant student-centered curricular revisions tied to educational psychological and cognitive science approaches that showcase quantifiable embedded signature assignments/assessments (ESAs) that are all focused on biomedical engineering. These approaches not only introduce the ERC students to the "essence" of engineering early on in their undergraduate or graduate program, but also engage the engineering students in situated, inductive, problem solving throughout course work in addition to interdisciplinary inductive learning facilitated by a combined socio-constructivist/ sociocultural theoretical approach to engineering curricular reform linked to their ERC lab work.[7] Research has revealed that this instructional/curricular approach with its group-based, collaborative focus is particularly effective in retaining underrepresented groups, in STEM education. Research conducted by Banks[8] posits that people of color learn best in collaborative settings matching their home experiences. Additionally, research conducted by member institution in the National Consortium for Graduate Degrees for Minorities in Engineering and Science, Inc. [9] has revealed that mentorship, which is best provided in group and collaborative situations facilitates underrepresented group retention.

Educational Psychology and Cognitive Science as Means of Transforming Engineering Curriculum

A long-term educational objective of this urban ERC's curricular reform research is to reform engineering education by applying well-established techniques borrowed from educational psychology and cognitive science to biomedical engineering. The measurements and methods for this approach include inductive, student-centered, active learning applied to real life engineering challenges and problems. This innovative perspective in engineering education reform is based on theoretical approaches with strong roots in educational psychology, cognitive science, and socio-constructivist/sociocultural theory.[3] [10, 11, 12, 13] Much of this work focuses on students' engagement in STEMS learning activities, in particular "active learning," "inquiry-based learning," "situated learning," and "problem-based learning," [3, 12] that includes participation in a variety of meaningful activities including problem-solving and critical thinking with real world engineering practice application. This is easily applicable in an ERC with test beds that are tied to coursework and with faculty mentorship in the ERC labs. The goal for inductively-based situated instruction is to develop and construct knowledge with a social perspective through physical and mental activities including hands-on experience in experimentation and investigation through observing, collecting and analyzing data to replicate research, group engagement, and exploring new inquiry approaches. This is the essence of a combined socio-constructivist/ sociocultural approach. [7] From this perspective, effective engineering educators must structure situated learning environments that foster experiences that enhance students' knowledge of engineering application in the real world. The guiding principles of socio-constructivist and sociocultural perspectives suggest that engineering educators utilize problems relevant to students and the engineering field and structure learning around primary concepts and students' suppositions. [13]

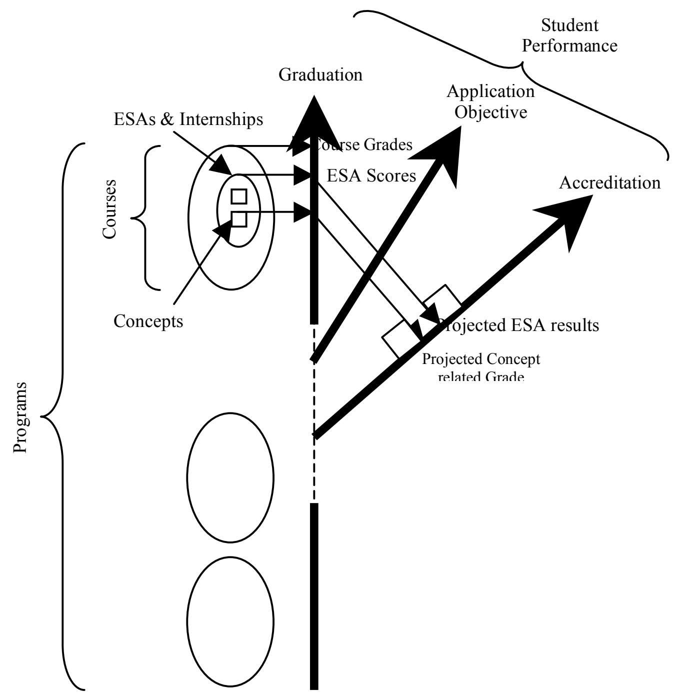
Some of the measurements and methods that have been or will be utilized in the ERC's educational programs at both the undergraduate and graduate levels have been developed and tested in science education settings in K-12 schools, but have not received significant attention in university settings to measure student learning and education program performance particularly in engineering professional schools.

The ERC faculty researchers are applying widely researched educational psychology and cognitive science principles and practices to the engineering curriculum that connects the ERC test bed lab work to powerful coursework. These practices include: (1) inductive, situated, student- centered instruction, (2) embedded signature assignments/assessments (including concept inventories and maps, rubric judged lab experiences, and course projects), and (3) value judged internship experiences in both our engineering courses.

Research Design and Methodology:

As previously described, the research design for the described engineering education program incorporates educational psychology related inductive instructional methodological approaches and assessment measures that are linked to socio-constructivist/sociocultural perspectives and learning units that are engaging for students (particularly appropriate for underrepresented groups) and are linked to real life engineering problem solving approaches. [3, 7] In an effort to decide which way to go with the BME curricular reform, the faculty researchers first collected student related data to find out where they are and which process would best meet the needs of the current BME ERC students and those the faculty wish to recruit into the BME ERC courses in an effort to meet the changing global needs of engineers for 2020. [1] As previously described, this paper is a "work in progress" effort as the faculty researchers are midstream in the BME curricular reform efforts. The researchers employed a baseline data, quasi-experimental research design. Baseline data, quasi experimental designed studies applied to engineering education include collection of baseline data at the commencement of the reform implementation and comparing it to post program assessments. [13] The ERC baseline data includes results from *access, retention* and *career* data collected from the current and alumni ERC students. This baseline data has led the faculty researchers to a design of comprehensive curriculum reform that is in the pilot stages. In addition to pre and post test (summative) data that they are now collecting resulting from our baseline results and reform efforts, the faculty researchers will be collecting and analyzing formative assessment data (ESAs) throughout the project to enable them to make just-in-time revisions to the curriculum throughout the reform/research process. Figure 1 (below) describes the ERC's powerful performance system that formatively and summatively monitors the progress and success of curriculum reform. The performance assessment has been constructed using embedded signature assessments. Past attempts of measuring the performance of BME students have relied on a single senior-level capstone design course and end-of-course surveys. The faculty researchers are now engaging in a direct and systematic assessment of student performance across entire programs. This assessment, which measures quantitative performance, does not increase greatly faculty workload and data collection; it builds upon and greatly enhances the current practices of evaluating and grading found in traditional engineering education curricula. Further it concisely aligns research efforts included in our BMES ERC test beds and thrusts with the curriculum that the students receive. Instructors in collaboration with ERC faculty define the ESAs and link desired program/course objectives to ESAs. This monitoring system produces immediate quantitative feedback for promptly addressing course and program strengths and weaknesses. Figure 1 (below) illustrates an innovative feedback loop. As shown in Figure 1, the vertical axis represents a progression toward graduation, whereas the inclined axis represents a progression toward other goals set by accreditation requirements and best practices.

Figure 1. Program Design Feedback Loop



The research questions for the BMES ERC's educational program curricular reform efforts include:
(1) What effect will inductively based, situated instruction play on student learning and program success?
(2) What is the efficacy of embedded signature assignments/assessments (ESAs) on measuring student learning from the reform?
(3) What effect will inductively based, situated instruction play on undergraduate and graduate student learning and preparation for the engineering field?
(4) What role does the curricular reform play in increasing recruitment and retention of underrepresented groups in engineering programs?

These four research questions are interrelated as the ERC's faculty researchers judge the ERC's educational reform success both by increases in engineering student learning and preparation for BME fields. They hypothesize that these curricular reform will dramatically increase engineering program success and ultimately, BME related employment success in comparison to the baseline data that has been collected. The faculty seek success of all of the engineering students while placing special emphasis on retention of underrepresented engineering students (URMs) as they believe, (through exploration of the education literature,[8 12, 14]) that the reform places a high emphasis by design on meeting the needs of these important groups. The faculty are measuring engineering efficacy of all students pre and post program as this is linked to student retention [15].

Overview of Measures and Instructional Methodologies:

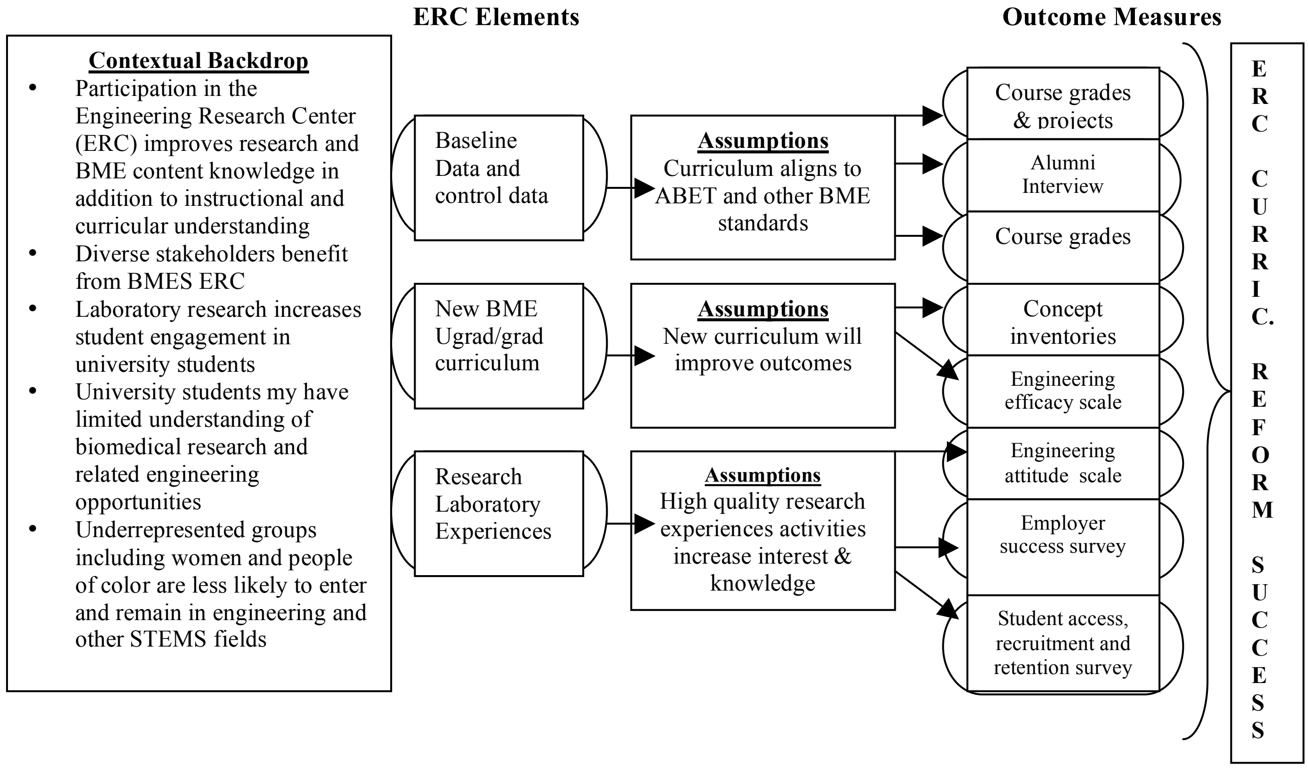
Both the instructional methods and the assessment measures that are utilized for this educational research project are innovative and involve active student engagement utilizing an inductive approach. *Inductively based situated instruction* is the primary instructional/curricular reform methodological approach. Tied to this curricular approach, embedded signature assignments/assessments are utilized as primary student learning measures. *Inductively-based, situated instruction* is described as a provision of instruction where students are provided with learner-centered problem-based instructional opportunities primarily focused on real world vignettes or workplace problems and involving solving vignette-based issues and situated, project-based problems individually and in cooperative groups using principles perspectives and practices that students have learned in courses. [3, 12, 13, 14] These are often collaborative experiences that build BME leadership skills and increase retention of underrepresented groups, and resulting solutions for these situated instructional/learning experiences are judged using carefully crafted numeric rubrics. *Embedded signature assignments/assessments (ESAs)* are critical assignments that are linked to accreditation standards and are formative assessment measures of course content in our curricular reform effort. They range from a criterion referenced examinations to group or solo projects aligned to the ERC test beds and thrusts. The ESAs offer proof of within course learning [15] and include various subtypes. Examples of ESAs that we use are: (1) vignette based problem-solving assignments, (2) rubric judged laboratory experiences from the test bed laboratories, (3) field based projects in ERC facilitated internships, (4) course specific concept inventories, (5) course examinations, and (6) cross course concept maps. *Rubric judged laboratory experiences* have often been applied to K-12 sciences coursework however they are somewhat novel to university course-based lab experiences. Rubrics for the laboratories are aligned to content standards (ABET standards and BME best practices [17]). Numeric scores are assigned to the rubrics allowing the course instructors to quantify human behavior for statistical analyses and comparison across groups. [16] *Concept inventories* have been used in education for decades. While these inventories are now applied in some engineering fields, they are not widely used in biomedical engineering. These inventories are multiple-choice surveys in which misnomers related to content are contrasted with concept truisms in an attempt to statistically judge increases in concept knowledge via instruction and lab experiences as pre and post test measures. *Concept maps* are maps that students create that connect concepts learned in courses to create a multimodal mega concept. *Value judged internships* are often used in education, social work or other human services professions where internships are required as a precursor to graduation. Engineering intern supervisors use numeric measures to judge the performance of the intern. These measures link the course content to the interns' field /lab based research practice in the ERC test bed labs. [16]

Our first concept inventory has been created and has been delivered to the first set of students pretest. It has been designed for a course entitled, *Rehabilitation Engineering*. An example question from the concept inventory are provided as an appendix to this paper. This is the first of several inventories that will be created for the project as content knowledge measures.

Data Collection:

In an effort to fully understand the direction of the BME focused ERC curricular research, the faculty researchers employ a comprehensive logic model, which included baseline data collection to describe the state of the participant engineering students in addition to collection of summative and formative data throughout the curricular reform effort in the ERC.

Figure 2: Education Logic Model

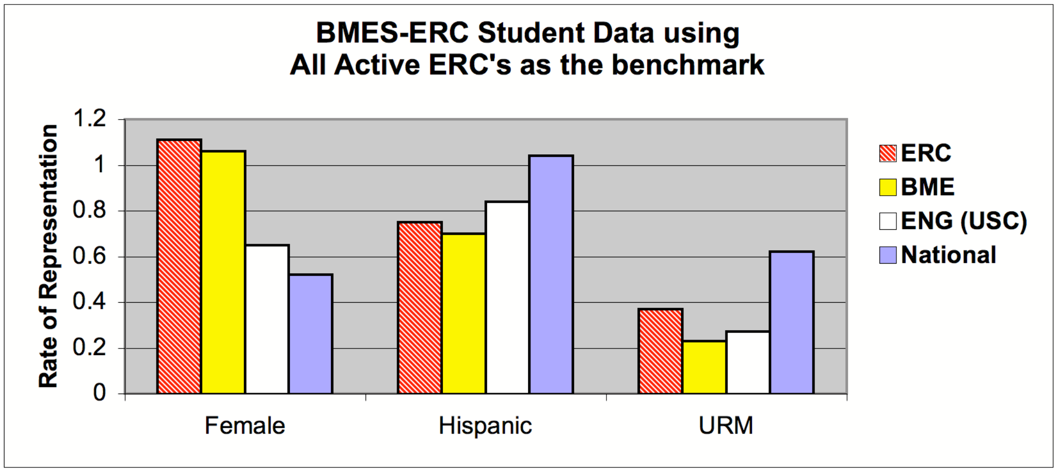


It should be noted that both baseline data (informing the reform design) and formative and summative instruments measure the outcomes of the curricular reform. Data collection mechanisms for establishing baseline data included student retention rates, student/alumni perceived success data, engineering efficacy data, and diversity data. This data is the primary focus of the results section of this paper as the reform is in pilot stages and the faculty researchers are in the process of collecting the first wave of outcome data on the reform. All baseline data will be collected beyond baseline to measure changes over time. Much of the baseline data was obtained via statistics gathered from the academic advisors in addition to alumni and current student interviews/surveys. Efficacy data was obtained via a student efficacy survey. Pretest and posttest concept inventory data will be presented at the conference, as the semester has not ended therefore pre-post test comparisons are forthcoming.

Preliminary Results:

Baseline data related to the ERC student participants reveal the following results. Figure 3 represents the underrepresented minority (URM) within the ERC, other university BME students at the university that are not a part of the ERC related coursework/research experiences, engineering at the university where the ERC is located and engineering students nationally.

Figure 3: URM representation

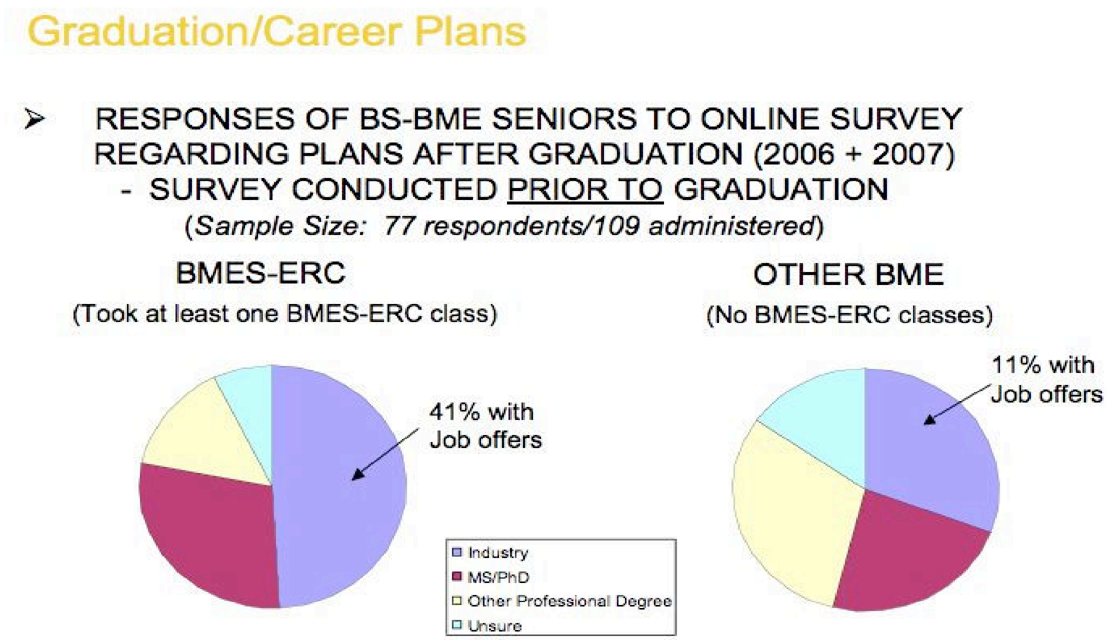


It should be noted that female participation in the ERC experiences far exceeds that of national data in engineering. This finding has led the researchers to look closer at the representation of ERC students from other URM. As such, as a baseline data point they have reviewed the representation of Hispanic and other underrepresented minorities. Accordingly, results reveal that Hispanic and other underrepresented groups are recruitment and retention targets. As such, the reform efforts with a social cognitive/socioconstructivist focus have been designed and implemented as these have been found to support these underrepresented subgroups.

A preliminary set of outcome data that provide the researchers with post graduation outcomes has been collected and analyzed. This data follows as Figure 4 (below).

The findings in Figure 4 demonstrate the ERC students predominantly go either to graduate programs post graduation our on to jobs. This is a preliminary measure of program success. Next steps related to this data is to survey employers related to the success of the ERC program and to compare to the program outcomes and employer success post curricular reform.

Figure 4- Survey of Career Plans



Another data set collected was biomedical Engineering efficacy. Twenty-nine students participated in the BME efficacy survey. Ninety-six percent were senior participants with 2 progressive degree participants, and all participants were in the course, BME 414, a third-fourth year biomedical engineering course that includes a component. An engineering efficacy scale was utilized to assess students' (1) general biomedical engineering knowledge of the field and (2) BME efficacy. The BME efficacy scale was adapted from a computer engineering efficacy scale. [18] This is an efficacy scale with 6 subscales. The subscales include: *problem solving confidence, trouble-shooting confidence, career encouragement, satisfaction with college major, career exploration,* and *course anxiety*. One primary purpose for this pilot is to test the validity and factor loading of the adapted subscales. At this time only descriptive statistics and preliminary correlations have been conducted as the instruments are in pilot stages of the study and the assessment measures are not at pre/post stages. Additionally, the participant number (N) was only 29, making statistical power questionable. Item analyses on the instruments were performed, however, in an effort to test the content and construct validity of the instruments. The data that follows represents one semester of preliminary efficacy and general chemical engineering knowledge emphasis data at pilot stages.

The table that follows (1) represents the overall efficacy of the students in BME 414 during Spring 2008 (the pilot semester). In general, BME undergraduate students are efficacious across subscales.

Table 1: Overall Mean and Standard Deviation: BMEES

BME Efficacy	*M*	*SD*
BMEES results	4.43	1.82

All surveys were based on a 6-point likert type scale. The overall mean of engineering efficacy of the group (Spring 2008) was 4.43 as represented in Table 1 (above). As previously described, this scale has six subscales. Multivariate analyses (pre and post) will be conducted once we have obtained two or more years of efficacy related data. The researchers also reviewed item analyses data for means comparisons. From this item analysis, several areas if interest are noted. Mean differences reveal that the BME student are confident in their ability to collaborate in laboratory and other academic settings. They prefer collaboration to solo activities. They prefer to use technology for application. They report high levels of confidence related to their major choice in chemical engineering. Interestingly, but perhaps not surprisingly, the student participants did not receive information nor encouragement about chemical engineering from any high school personnel. This finding speaks to the need for comprehensive outreach to K12 to provide information to potential students. This is a planned focus for year two of this project.

Table 2 below describes engineering efficacy across subscales. There are 6 tested subscales of this efficacy scales for this scale. They include: *trouble shooting confidence, problem solving confidence, career encouragement, satisfaction with college, career exploration and course anxiety.* The mean distribution by subscale is included in Table 2 below.

Table 2: Preliminary Analyses of Factors associated with Engineering Efficacy

Factor	*M*	*SD*
Problem Solving Confidence	4.72	1.29
Trouble-shooting Confidence	4.08	1.79
Career Encouragement	2.77	1.92
Satisfaction with College	4.43	.9769
Career Exploration	4.54	1.27
Course Anxiety	4.17	2.879

When reviewing factors from the subscales, the need for career encouragement was underscored. The mean efficacy in this area is only 2.77 in this subscale. Course anxiety proved to be potentially an area of need. While the mean was 4.17 the range of answers varied greatest (SD=2.879).

This data reveals that engineering students are efficacious however there are individual variations across groups and in specific areas associated with efficacy. The research team's next steps with this data are to compare it to knowledge measures (grades and concept inventory post tests) at the semester's end.

Implications and Directions for Research:

The direction for this research is guided by the fact that this ERC is a ten-year project that is in the process of curricular reform in the context of a research university. The faculty is in the process of collecting comprehensive data sets that will create profiles of engineering graduates that will provide the field with a new kind of engineer with an inductive focus, strong leadership skills and a global focus in an effort to meet the changing needs of engineers in the year 2020 as recognized by the National Association of Engineering.

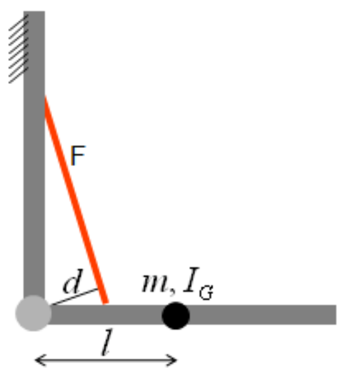
References

1. **NAE**, 2004, "*The Engineer of 2020*," National Academy of Engineering, The National Academy Press, Washington DC.
2. **NAE**, 2005, "*Educating the Engineer of 2020*," National Academy of Engineering, The National Academy Press, Washington DC.
3. **Prince, M.J., Felder, R. M.** 2006. "Inductive teaching and learning methods: definitions, Comparisons, and research bases." *Journal of Engineering Education.* Vol 101. 4 123-137.
4. **NSB** (National Science Board), 2003, "*The Science and Engineering Workforce: Realizing America's Potentials*," Report 03-69, Arlington, VA, National Science Foundation, Available online at http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf, Accessed July 8, 2005.
5. **Wankat, P. C., R. M. Felder, K. A. Smith and F. S. Oreowicz,** 2002, "The Engineering Approach to the Scholarship of Teaching and Learning," pp. 217-237 in *Disciplinary Styles in the Scholarship of Teaching and Learning: Exploring Common Ground*, M. T. Huber and S. Morreales, eds., Washington, D.C., American Association for Higher Education, Available online at http://www.ncsu.edu/fielder~public/papers/Scholarship_chapter.pdf, Accessed July 8, 2005.
6. **Arreola, R., M. Theall, and L. Aleamoni,** 2003, "Beyond Scholarship: Recognizing the Multiple Roles of the Professoriate," Presented at the *2003 American Educational Research Association convention*. Available on line at http://www.cedanet.com/meta/Beynd%20Scholarship.pdf, Accessed April 19, 2005.
7. **Mayer, R. E.** 2007, *Learning And Instruction.* Thousand Oaks: Pearson.
8. **Banks, J.** 2004. *Handbook of Multicultural Education.* LEA: N.J.
9. **Arlow J., and Neustadt, I.** 2001, "*UML and the Unified Process: Practical Object-Oriented Analysis and Design.*" Boston: Addison-Wesley Pub Co..
10. **Alexander, P.** 2007. "Bridging cognition and socioculturalism within conceptual change research: unnecessary foray or unachievable feat?" *Educational Psychologist.* Vol. 24 1.
11. **Ormrod, J.E**. 2008. *Educational Psychology: Developing Learners.* 6th Edition. Upper Saddle River, N.J.:Merrill.
12. **Anderson, L., and Krathwohl, D.** Eds. 2000, 2004, "*A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*." Boston, MA: Longman.
13. **Brooks, J., & Brooks, M.** 1993. *The case for a constructivist classroom.* Alexandra, VA: Association for Supervision and Curriculum Development.
14. **Bybee, R.** 2002. *Learning science and the science of learning*. Arlington, VA: NSTA Press.
15. **Pecheone, R. and Chung, R.** 2006. "Evidence in Teacher Education: The Performance Assessment of California Teachers." *Journal of Teacher Education*. vol. 57: pp. 22 - 36.
16. **Clark, R. E. & Estes**, F. 2002. *Turning Research Into Results: A Guide to Selecting the Right Performance Solutions*. Atlanta, GA.: CEP Press.
17. **Shuman, L. J., Besterfield-Sacre, M. and J. McGourty,** 2005, "The ABET Professionals Skills – Can they be taught? Can they be assessed?" *Journal of Engineering Education,* Vol. 94, No. 1, pp. 41-56.
18. **Hutchison, M.A., Follman, D. K., Sumpter, M., and Bodner, G. M.** 2004. "Factors influencing the self-efficacy beliefs of first year engineering students." *Journal of Engineering Education.* Vol. 101. 1. 39-47.

Sample Concept Inventory Questions

1) In the figure shown below, the upper arm is fixed in a vertical position and a single muscle applies a force F to maintain the lower arm in horizontal position as shown in the figure. What is the magnitude of the force F if the muscle moment arm is equal to d ?

A. $\frac{mgl}{d}$ B. $mgld$ C. $\frac{mg}{ld}$ D. mg



2) [C1] – Consider the musculoskeletal system shown in the figure below. The upper arm is fixed in a vertical position but the forearm is free to rotate about the elbow joint and is actuated by two antagonistic muscles: Biceps and Triceps. F_T , F_B , and d_T , d_B are the forces and moment arms of the muscles, respectively. The mass and mass moment of inertia of the forearm are m and I_G . If the forearm is released from the horizontal position as shown in the figure and $F_T d_T = F_B d_B$,

A. The forearm will stay still in horizontal position and will not move
B. The forearm will move upward with constant velocity
C. The forearm will start moving upward with variable acceleration
D. The forearm will start moving downward with variable acceleration

3) [C1] – Which one of the following equations describe the rotational movement of the forearm in question (3) above about Z-axis? $\ddot{\theta}$ is the angular acceleration of the forearm about Z-axis.

A. $\ddot{\theta} = \frac{F_T d_T - F_B d_B - mgl}{I_G + ml^2}$ C. $\ddot{\theta} = \frac{F_B d_B - F_T d_T - mgl}{I_G + ml^2}$

B. $\ddot{\theta} = \frac{mgl}{I_G + ml^2}$ D. $\ddot{\theta} = \frac{mgl}{I_G}$