**A Biomedical Engineering Course of Study at the Secondary School Level**

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**Abstract**

In an effort to increase awareness of and offer support in science and engineering among pre-college students the Biomimetic MicroElectronic Systems Engineering Research Center (BMES ERC) at the University of Southern California (USC) has partnered with a Los Angeles high school to establish the Engineering for Health Academy (EHA). The Academy offers students in grades 10 through 12 a new and innovative course of study comprised of 4 integrated classes focused on biomedical engineering.  Biomedical engineering curriculum has been developed and embedded in the EHA core classes including chemistry, physiology, computer sciences, and physics. In partnership with USC, EHA students are exposed to and learn about the field of biomedical engineering, develop technical and communication skills, and conduct investigatory projects that are presented at the annual Bravo/USC science and engineering fair. As seniors, EHA students enroll in the Research Experience capstone class where they become integral members of a research team at USC. This capstone class enables students to utilize the factual information and practical skills they have accumulated in the EHA core courses and put them into practice in a research environment. EHA students on average outscore their non-EHA high school peers on district and state science assessment measurements, self-report keen interest in science and engineering, elect to participate in summer enrichment programs, and apply to 4-year colleges and universities in STEM fields. The EHA program will longitudinally follows the students as they progress through the high school program and graduate onto college.

**Introduction**

Engineering plays a critical role in the development, prosperity and security of a nation. In order for the U.S. to remain competitive on a global scale, it is imperative that a large and well-prepared engineering workforce is maintained. According to the U.S. Bureau of Labor Statistics employment of engineers is expected to grow by 11 percent over the 2008–18 decade [1].Despite this demand for engineers, there has been a steady decline in the number of U.S. high school students who plan to major in engineering in college and fewer potential engineering majors are completing rigorous college preparatory programs [2].Furthermore,economic, educational, and political factors have created challenges in meeting projected domestic engineering labor force demands.

The U.S. labor force will be more diverse in the near future. As a result of a higher population growth among minorities their share of the labor force is projected to increase significantly. By 2018 it is projected that blacks will comprise 12.1 percent and Hispanics 17.6 percent of the total labor force [1]. In California, the changes in demography are even more pronounced. Approximately 58 percent of the state’s population is minorities with Hispanics forming the largest subgroup at 37 percent of the total [3].

Although the proportions of blacks and Hispanics in science and engineering occupationshave grown over time these groups remain largely underrepresented in engineering schools and engineering jobs in the U.S. relative to their proportions in the population [4]. In general, blacks and Hispanics are less likely than whites and Asians/Pacific Islanders to graduate from high school, to enroll in college, and to graduate from college [5]. If the U.S. is to reach its projected engineering workforce target, recruitment among underrepresented groups at an early stage in their education would be constructive. The development and implementation of a rigorous yet supportive educational environment where high school students are introduced to and participate in a student-centered engineering curriculum can be a strategy to help meet the nation’s long-term demand for engineers.

In an effort to increase awareness of and offer support in science and engineering among pre-college students, including under-represented minorities, the Biomimetic MicroElectronic Systems Engineering Research Center (BMES ERC) at the University of Southern California has partnered with Francisco Bravo Medical Magnet High School to establish the Engineering for Health Academy (EHA). The Academy offers students in grades 10 through 12 a new and innovative multi-year course of study focused on biomedical engineering. The EHA has four major goals: 1) to introduce high school students to the relationship between engineering and the medical sciences; 2) to design and implement a series of integrated core courses that are experiential in nature, standards-aligned, and directly relate content knowledge and skill mastery to student-centered engineering projects; 3) to place third year EHA students in USC research laboratories as part of a capstone course; and 4) to prepare students to undertake and succeed in a rigorous postsecondary science and engineering education pathway.

**Implementation and Results**

EHA Organization

The Engineering for Health Academy (EHA) is designed as a small learning community (SLC) within the context of the larger comprehensive high school. The Small Learning Community model subdivides the school population into smaller, autonomous groups of students and teachers, creating a more personalized learning environment to better meet the needs of students. SLCs have a unifying vision, rigorous standards-based curriculum, community engagement, and teacher professional development. Research shows that small learning communities have the necessary elements to counter the inherent negative effects of poverty and poor academic achievement for low-income and/or students of color [6,7,8].

The major goals of the Engineering for Health Academy program are to introduce high school students, including under-represented minorities, to the broad spectrum of biomedical engineering (BME) career opportunities (Table 1). EHA students make a three year commitment to the program beginning in the 10th grade and transition through a series of 4 integrated core courses (chemistry, physiology, computer sciences, and physics) in grades 10 through 12. Each EHA course is standards-aligned, rich in relevant hands-on activities, project-oriented and meets high school graduation and University of California and California State University (UC/CSU) admissions requirements. Curricular development is driven by current and future anticipated needs of the BME field so that graduating EHA students will have advanced preparation for the demands of a rigorous post-secondary college curriculum in biomedical engineering.

Table 1: Breakdown of EHA students according to grade level, gender and demographics.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Grade** | **No. of students** | **No. (%) of Males** | **No. (%) of Females** | **No. (%) of Asians** | **No. (%) of Blacks** | **No. (%) of Whites** | **No. (%) of Hispanics** |
| **10th** | 27 | 12 (44.4) | 15 (55.5) | 8 (29.6) | 1 (3.7) | 4 (14.8) | 14 (51.8) |
| **11th** | 28 | 14 (50) | 14 (50) | 4 (14.2) | 0 (0) | 4 (14.2) | 20 (71.4) |
| **12th** | 17 | 5 (29.4) | 12 (70.6) | 2 (11.7) | 1 (5.8) | 2 (11.7) | 12 (70.6) |
| **Total** | 72 | 31 (43.1) | 41 (56.9) | 14 (19.4) | 2 (2.8) | 10 (13.9) | 46 (63.9) |

Biomedical engineering is a unifying theme for each course and there is a horizontal (over-time) integration of content knowledge and skills development. The use of technology is embedded throughout the program. Students employ appropriate technologies as tools to make measurements and use computers to analyze, store, transmit and present data in tabular and graphical forms. EHA students learn to use sophisticated instruments as they relate to in-class projects. Furthermore, familiarity with technology helps prepare students for college majors in science, engineering, math and technology. The content knowledge and technical skills developed in each of the core courses prepares students for success in the research experience class they take in their senior year.

EHA Capstone Class

This year marks the first time a cohort of students will transition through the entire 3-year EHA syllabus. Seventeen students who entered the program as 10th graders are currently enrolled in the Research Experience class as seniors. These students are matched with 9 different USC laboratories and spend a minimum of two hours every school day working as part of a research team on an engineering project. Mentoring is a critical component of this capstone class. USC postdoctoral fellows and graduate and undergraduate students help the EHA seniors navigate the challenging transition from a structured high school classroom into a university research environment.

EHA students enrolled in the Research Experience class receive 10 course unit credits that count toward their UC/CSU high school graduation requirements. This capstone class enables students to utilize the factual information and technical skills they acquired in the EHA core classes and put them into practice in a research environment. It also increases the students’ self-efficacy and prepares them for the rigors of a college science and engineering course of study.

As part of the capstone class students are required to present their research findings at a seminar series scheduled midway through the program. Each presentation is 15 minutes in duration and is followed by a question and answer session. Laboratory principle investigators, USC mentors, and fellow EHA students attend these seminars and learn about the broad spectrum of EHA-associated research topics. The feedback students receive during the seminars helps them in the preparation of posters that they present at the annual USC/Bravo Science and Engineering Fair towards the end of the school year.

Mentoring

Mentoring is central to all aspects of the EHA program. USC graduate students meet with the high school students on a weekly basis to help them in their core EHA classes. Mentors provide a supportive environment where EHA students receive guidance with their class work, assistance with laboratory investigations, and help in the design and implementation of science fair projects. Oftentimes, mentors provide a different perspective than the classroom teacher, and this may help the high school students better understand a concept or approach a solution to a problem from a different point of view. Many high school students struggle in chemistry and physics, classes that are fundamental to biomedical engineering. Having mentors available to assists in these courses helps assure that the students receive a solid foundation in the physical sciences and better prepares them for the academic demands of college.

Mentoring is particularly important in the Research Experience capstone class. In partnership with their mentors the EHA students develop and execute an appropriate yearlong research project. Mentors guide the EHA students in the formulation of scientific hypotheses and experimental designs to test those hypotheses. They train the students in scientific protocols and methodologies, help them collect and analyze data, and draw defensible conclusions.

Mentors also serve as role models to the EHA students. All of the mentors have developed the knowledge and skills necessary to gain admission to and be successful at a top tier research institution such as USC. The mentors share their own experiences, life stories, and academic strategies with the aspiring high school students.  They offer advice on study habits, give tips on time management, and make suggestions related to the college application and financial aid processes. Mentors play a significant role in the EHA students’ attainment of knowledge, mastery of technical acumen and development of life skills. Through their example, mentors initiate the young scholars into the culture of the science and engineering communities and their influence will have lifelong positive implications.

EHA students in the Research Experience capstone class become mentors themselves as part of the Science for Life outreach program [9] at a local elementary school. The EHA students go into 3rd, 4th and 5th grade classrooms and guide elementary school students through a series of hands-on activities that relate research conducted at USC to California state science standards. The interest and enthusiasm the high school students exhibit towards science and engineering is authentic and contagious. It exposes the younger students to the excitement of scientific discovery and helps them understand the relevance of their science classes. Bravo EHA students receive service learning credit for their work with the elementary students. These credits count toward their high school graduation requirements. But, more importantly, mentoring helps to create and sustain a *culture of connectivity* and inculcates the idea of community service.

Science and Engineering Fairs

All EHA students, not just students enrolled in the Research Experience capstone class, are required to work on a research project every year they are in the program. Students may work individually or as a team. As expected, the projects typically become successively more complicated and detailed as the students progress though the EHA program, culminating in highly sophisticated projects that reflect the work completed as part of the capstone class. Working with EHA teachers and USC graduate student mentors, students decide upon projects that are of interest to them and feasible to undertake. Table 2 summarizes the number of science fair projects and their respective categories according to grade level in the 2010-2011 academic year. Students are provided guidance in translating science inquiry into testable hypothesizes and in understanding critical features of the scientific method including objectivity, reproducibility, reliability, and precision.

Table 2: EHA Science and Engineering Fair Projects

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | | **Categories** | | | | | | | | |
| **Grade Level** | **No.**  **of**  **projects** | **Biochem/ Molecular Biology** | **Behavioral Sciences** | **Botany** | **Chemistry** | **ENG**  **Applications** | **ENG**  **Research** | **Environ. Manage.** | **Micro-biology** | **Physio-**  **logy** |
| **10** | **16** |  |  | **2** | **8** | **2** | **2** | **2** |  |  |
| **11** | **13** |  | **7** |  |  | **1** | **2** |  | **1** | **2** |
| **12** | **15** | **3** | **3** |  |  | **4** | **3** | **1** |  | **1** |
| **Total** | **44** | **3** | **10** | **2** | **8** | **7** | **7** | **3** | **1** | **3** |

Professionals from USC and other institutes of higher education serve as judges at the fair. Depending on the quality of their work, select students are eligible to participate at the Los Angeles County and California State Science and Engineering fairs. A total of 12 science fair projects are allowed to advance to the Los Angeles County Science and Engineering Fair from each participating high school. This year 6 of the 12 projects from Bravo eligible to be presented at the County level were completed by EHA students. Five of these projects went on to win awards at the County Fair, three of which qualified to compete at the California State level.

Recruitment

Recruitment for the Engineering for Health Academy begins in the 9th grade. All 9th graders are administered the Science Composite Index (SCI) [10] which measures student interest and motivation in science in both formal and informal contexts. SCI results are used to identify potential EHA students who are then encouraged to learn more about the EHA program. Information about EHA is advertised around the high school on bulletin boards, flyers, PA announcements and posted on the school website. An EHA table is set–up at an annual curriculum fair and is staffed by current EHA students who talk about the program and answer questions. Informational lunch meetings are scheduled just before class selections are made so that prospective students can meet with EHA teachers and current students. Science and math teachers talk with their students about the EHA and they are encouraged to recommend students to the program. The USC/Bravo Science and Engineering Fair is an effective forum to inform students about the EHA as it showcases the types of projects and interesting questions undertaken by EHA students. Students who are interested in joining the EHA submit an application and solicit teacher recommendations. The application material is reviewed by a committee composed of EHA teachers, the EHA counselor, and a representative from USC. Students admitted to the program are required to obtain parental permission and are asked to make a 3-year commitment.

Program Assessment

Program assessment is a key component of the Engineering for Health Academy. Measurement instruments serve as formative assessments and enable teachers and mentors to monitor student interests, motivation and engagement as well as their competency in science and engineering. Analysis and interpretation of the assessments drive curricular modifications to meet the students’ needs. The assessments are also used for summative evaluation of the overall program

A variety of measurements and assessment instruments are employed including: results on the California Standardized Tests (CST) in chemistry and science, the number of students applying to 4-year institutes of higher education, the choice of college major, and the quality of projects entered into the science and engineering fair. The CSTs are designed by California educators and test developers specifically for California. They measure students' progress toward achieving California's state-adopted academic content standards, which describe what students should know and be able to do in each grade and subject tested. The objective is to have all students proficient in each area tested. Comparison of CST results in chemistry is shown in Figure 1 for EHA and non-EHA students at Bravo. Students take the CST chemistry assessment as 10th graders after completing their high school chemistry class. The data indicate that while only 37% of Bravo non-EHA students are proficient or advanced in chemistry, 65% of the EHA students attain these levels. Figure 2 show the comparison between EHA and non-EHA students on the CST science assessment that they are administered in their senior year. These results indicate that 82 % of the EHA students demonstrate proficiency as compared to 55 % of their non-EHA peers.

Figure 1: Comparison of CST chemistry results between EHA students and non-EHA students at Bravo. FBB=far below basic, BB=below basic, B=basic, P=proficient, A=advanced

Figure 2: Comparison of CST science results between EHA students and non-EHA students at Bravo. FBB=far below basic, BB=below basic, B=basic, P=proficient, A=advanced.

College Admissions

A major objective of the EHA program is to introduce high school students to biomedical engineering so that they may consider it as a career option. All EHA seniors have applied to college to continue their education. As seen in Table 3 most EHA students have accepted positions at public institutes of higher education. A major factor determining influencing this decision is economics. Tuition at public colleges/universities is, on average, significantly less expensive than at private institutions. Most of the EHA seniors are from families with limited financial resources. Each of the students who plan on attending private universities has received scholarships and financial aid packages that cover all or most of the cost of tuition. Another factor that influences choice of college is location. Most of the EHA students will be the first in their families to attend college and many of the students indicate that they are under some pressure from their families to attend college relatively close to home. All but three of the students will be attending colleges in California. The three students going to private colleges will be going out of state.

Table 3: Type of college and intended major of EHA seniors

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Type of Institution** | | **Intended College Major** | | | |
| Public | Private | Engineering | Biology/  Premed | Computer Sciences | Other |
| No. of Students | 14 | 3 | 12 | 2 | 1 | 2 |

Conclusion

The goals and objectives of the Engineering for Health Academy are to increase student awareness, especially among under-represented minorities, of career opportunities in science, engineering and technology; create a small learning community that provides students with a personalized and supportive learning environment and incorporates a focused vision, rigorous standards –based curriculum, and collaborative community engagement; and increase science and math literacy, particularly in chemistry and physics among students who respond to a real world “hands on” approach to instruction.

In its third year of implementation, the EHA currently has 72 students participating in the program. Students enter the academy in the 10th grade and are asked to make a three year commitment to the program. Students enroll in 4 core classes each of which has a biomedical engineering focus, offers honors credit, and meets requirements for admission to the University of California and California State University systems. As seniors, EHA students participate in a capstone class that matches them with research laboratories at the University of Southern California. This class offers the students the opportunity to work as part of a team on cutting-edge research topics.

Each year that they are in the program, EHA students are required to undertake a science fair project. Typically, the projects become more sophisticated as the students progress through the program and gain scientific knowledge and skills. Science fair projects conducted as part of the capstone class are of very high caliper and reflect the expertise developed by the students over the three years of the program.

Mentoring is a key component of the EHA initiative. It is interwoven throughout the program and it facilitates the establishment of a *culture of connectivity* in which mentors pass acquired knowledge and skills onto successively younger generations of students. This integrated mentoring conduit begins with senior USC faculty researchers and proceeds to students at the university, high school, and elementary school levels. Through their example, mentors initiate the young scholars into the culture of the science and engineering communities and their influence will have lifelong positive implications.

Assessment of the program indicates that students are achieving proficiency in science to a greater degree than their non-EHA counterparts at the same high school. Many of the science fair projects conducted by EHA students have won awards at the high school, county and state competition levels. All of the EHA seniors have decided to attend college with eighty-eight percent declaring a STEM major and, significantly, seventy-one percent choosing to major in an engineering field.

These findings support the hypotheses that introducing high school students to biomedical engineering in a rigorous but supportive learning environment will result in students choosing to pursue STEM and engineering majors at the post-secondary level. The Engineering for Health Academy may serve as an educational model to increase the number of students, including underrepresented and female students entering the STEM workforce.

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