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## **AC 2011-2368: BUILDING ENGINEERS AND MENTORS: A MODEL FOR STUDENT-LED ENGINEERING OUTREACH**

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# **Building Engineers and Mentors:**

## **A Model for Student-Led Engineering Outreach**

### **Introduction**

Two years ago, it became apparent to us that there was a strong desire to participate in engineering-related outreach on the part of the students. Many student organizations such as the Hispanic Engineers and Scientists, Pi Tau Sigma, Society of Women Engineers and other similar groups each had their own unique k-12 outreach programs while other organizations like Engineering 4 Kids Day were piloting their own unique contributions. In interviewing undergraduate students we found consistency in the obstacles that they faced: (1) students were either unaware of the opportunities for outreach or did not find a right match with the organizations that provided such opportunities; (2) outreach was considered insignificant compared to their coursework. There was a general attitude that outreach was not “technical enough” for engineers and the benefits of community service were not apparent enough to students; (3) it was hard to train mentors that were capable of teaching science and engineering concepts to a younger audience.

We believe that community service builds strong, empathetic leaders. With this in mind, we tackled this design problem like engineers would and specified the user needs of students like ourselves, our k-12 mentees, and the university—our primary stakeholders. After many brainstorming sessions, we concluded that we have three main user requirements: (1) professional development, (2) the need for practical, technical experience—a chance to put our engineering education into practice, and (3) formal mentor training.

We used results from a recent a study<sup>1</sup> performed by the Lawrence Hall of Science (LHS) and our own experiences to define user requirements for our k-12 mentees including the need for more exposure to science and engineering as well as the need for fun, engaging activities. Additionally, we defined some user requirements for our university, which include the need to recruit potential students and conduct outreach within the financial constraints of a public university. The slogan for the College of Engineering is “Educating Leaders, Creating Knowledge, Serving Society” and hence we aimed to meet the need to develop alumni with strong leadership skills.

In an effort to address these problems and meet the user requirements, we joined efforts with our fellow student leaders and created Building Engineers and Mentors (**BEAM**), which is now a student organization, and a course at the university. BEAM is a group of engineering and science students that develop and teach hands-on lesson plans at K-12 schools in the local community. We also train college students to be effective mentors, role models, and leaders in their

community. Being students ourselves, we understand that the best way to learn is by teaching and by doing. Participants can earn course credit while improving their mentoring and leadership skills.

BEAM operates a student-run class to train our mentors and to develop leadership skills in our members. BEAM serves as a model for effective student-led outreach and education partnerships between universities and their surrounding educational institutions. Our program has been designed to contribute to greater diversity and access to engineering while serving the needs of our primary stakeholders. For two and a half years, we have planned, implemented, assessed, and redesigned a flexible organization to achieve our vision: to impact the future of students in our community through hands-on learning. This paper will explain the details of our program, show preliminary quantitative and qualitative evaluations, and discuss our plans for the future.

## **Organization and Methods Employed**

BEAM was founded with the support of the College of Engineering, several faculty members, and the university's Public Service Center. In the fall semester of 2010, BEAM evolved into a student-taught course and team of 60 mentors who teach at eleven k-12 schools in the surrounding community. The following subsections describe details of this work.

### **What is unique about BEAM?**

BEAM is structured to encourage mentors to take initiative and develop their leadership skills early on in their involvement. For example, at the end of the 10-week semester, mentors take ownership of the curriculum design process by creating unique lesson plans. The students have the opportunity to not only execute a set curriculum at the mentoring sites, but also gain experience in the curriculum design process. These lesson plans are then implemented and carried out by the mentors as the final lesson plan for the school semester. By doing so, the student mentors involved with BEAM take on the role of teachers and leaders instead of just volunteers working with k-12 students.

Another unique aspect of the program is the coupling of engineering outreach with a mentoring training course, which is described below. Students concurrently work in the field and also have an engineering and conceptual basis in a course. Our program is method-driven in that students are given training, relevant scientific knowledge, and reflective discussion opportunities to improve the quality of mentoring.

The program is also unique in that it offers different levels of involvement for the mentors. On one hand, students can enroll in the BEAM mentor training course and teach at an after-school program. However, BEAM has partnered with the Lawrence Hall of Science and its Ingenuity Lab to offer students a chance to guest mentor once to see if BEAM is right for them. This flexible system allows involvement from college students who are passionate about teaching, whether they can devote a large amount of time or only for a few hours a month.

## **How is BEAM connected to other outreach programs?**

BEAM adheres to engineering education principles. We designed BEAM with the following pedagogical practices in mind: (1) adherence to the ABET Criteria used for graduating engineers; (2) use of an elementary 5-Step Engineering Design Process for teaching engineering principles; (3) use of Bloom's Taxonomy<sup>4</sup> for training mentors in levels of learning and development of appropriate lesson plans; and the use of learning styles as defined by Felder<sup>3</sup> to create inclusive educational plans. With these principles in mind, we developed the learning objectives for BEAM mentors and mentees. These learning objectives are outlined below.

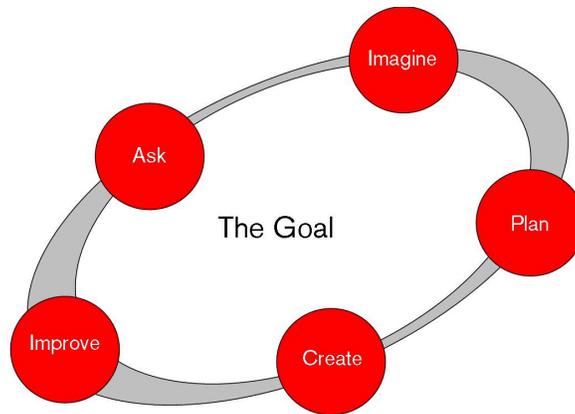
### **Mentor Learning Objectives:**

1. Explain the 8 learning style domains, the 6 levels of learning (Bloom's Taxonomy) and the ABET learning outcome objectives.
2. Apply the elementary 5 step design process.
3. Design a k-12 level teaching plan for an applied science or engineering topic that address the eight learning style domains (active-reflective, verbal-visual, intuitive-sensing, global-sequential).
4. Develop lesson plans that implement the six levels of learning as defined by Bloom's taxonomy (L1-L6).
5. Develop assessment tools to evaluate the effectiveness of teaching plans and mentoring.
6. Function effectively on a team, with effectiveness being determined by instructor observation, peer ratings, and self-assessment.
7. Create learning environments that foster all elements of the ABET learning outcome objectives.

### **Mentee Learning Objectives**

1. Identify an important contemporary technical challenge of a regional, national, or global nature that involves or utilizes engineering.
2. Describe the basic engineering design process and its use in solving technical challenges.
3. Discuss ways engineers might make important contributions to solving problems.
4. Remember or summarize key facts and concepts taught in each lesson plan.
5. Explain technical concepts in their own words.

BEAM uses the 5-step design process (Figure 1) developed by Boston Museum of Science (Engineering is Elementary)<sup>5</sup> in our education plans owing to its simplistic terminology and ease of use in the k-12 domain.



**Figure 1: The Engineering is Elementary® 5-Step Engineering Design Process**

### **Protocol for conducting outreach**

BEAM has a standard protocol for conducting engineering outreach. For 10 weeks of the semester, our mentors volunteer at several after school programs for about 1.5 hours per week. Volunteer sessions occur Tuesdays-Fridays. Mentors receive training on the week's lesson on Monday nights. More detail of this mentor training can be found in the following section. In the Fall of 2010 we sent mentors to 11 after school programs at 8 elementary schools and 2 high schools. Some of our mentors also worked an hour per week at the LHS Ingenuity Lab. We call each program a "site" and each site is managed by a "site leader," an experienced BEAM mentor.

In the Fall of 2010 there were a total of about 150 mentees participating in our after school programs. We maintain a high mentor-to-mentee ratio (usually 1:3 or 1:4) at our sites. Our mentors are assigned to a few students with whom they will work with personally for the entire semester.

We design lessons and activities that tap into kids' natural inclination to tinker and explore, making sure that every lesson plan has a hands-on component, which allows the mentees to design and build something and/or engage in an active exploration. Most of our activities are completed in teams, emphasizing communication and joint problem-solving. Lesson plans fall into three categories: *module-based*, *project-based*, or *challenge-based*. Table 1 gives a description of each category. The curriculum team ensures that the syllabus covers concepts from all the major engineering disciplines. The list of lesson plans for Fall 2010 is given in Table 2.

When developing lesson plans, we take full advantage of the fairly comprehensive collections of engineering lesson plans that already exist including but not limited to: [teachengineering.org](http://teachengineering.org), [howtosmile.org](http://howtosmile.org), [make magazine](http://make-magazine.com), [Instructables.com](http://Instructables.com), etc. As we gain experience in designing lesson plans we hope to eventually make our own contributions to these communities.

<b>Module-based</b>	These lesson plans teach an overarching engineering concept or principle through the use of "modules." Each module is a different activity that helps students understand the concept. The goal of these lessons is to break down the overall concept into more manageable sections. Mentors have the choice of dividing the mentees into groups that rotate through each module.
<b>Challenge-based</b>	Challenges focus on the engineering design process. Mentees are given a challenge and are asked to go through the design process to come up with a solution, test it, and redesign it.
<b>Project-based</b>	These projects are designed to succeed. They provide working models and examples that prominently illustrate certain engineering concepts. Mentors guide the mentees in building the project.

**Table 1: Description of lesson types.**

<b>Week</b>	<b>High School Lesson Plan (<i>lesson plan type</i>)</b>	<b>Elementary School (<i>lesson plan type</i>)</b>
1	Build a kinetic sculpture (challenge)	Build a lava lamp (project)
2	Build LED Lightbox (project)	Build kinetic sculpture (challenge)
3	Build LED Lightbox (project)	Build Stomp Rocket (challenge)
4	Build a skyscraper (challenge)	Build a skyscraper (challenge)
5	Build a skyscraper, week 2 (challenge)	Build a skyscraper, week 2 (challenge)
6	Build a stomp rocket (challenge)	Learn about acid rain (module)
7	Build a scribbling machine (challenge)	Build a scribbling machine (challenge)
8	Learn about polymers (module)	Learn about polymers (module)
9	Build a heat shield (challenge)	Build a heat shield (challenge)
10	Mentor-developed lesson plan	Mentor-developed lesson plan

**Table 2: Syllabus for Fall 2010**

### **Mentor Training**

Mentor training is an important aspect of the BEAM program and there has been considerable effort in developing appropriate protocols for this educational process. In order to accomplish the goal of the program to ensure the quality of mentorship, we train our mentors through a semester-long course. The course comprises of a mentor training workshop, a 10-week weekly class with a guest lecture series (which usually falls on Monday nights), and a final project. Mentors can receive 2-3 units for taking the course. Course attendance is mandatory for all

receiving units and is strongly encouraged for mentors who decide to not take the course for units.

The mentor training workshop is a day-long event held at the Lawrence Hall of Science and is held the weekend before the first week of mentoring. Students participating in the BEAM program and mentoring course are required to attend this training. This event features a keynote speaker and several rotating workshops. Each workshop is given by an educational professional and features a different mentoring technique.

The guest lecture series invites professors, graduate students, and educational professionals to give a half hour lecture on topics related to the state of science education and their own mentoring experiences. These lectures occur during the Monday night classes and are meant to inspire and stimulate productive conversations among the mentors.

Since BEAM is a science and engineering educational outreach group, the remaining hour of the mentoring course is allocated for teaching students the scientific background and to familiarize students with the activity of the week. Half an hour is dedicated to the theoretical concepts for each lesson. This is important because the participating mentors are from various engineering and science (or even non-science) backgrounds, and the lesson plans taught each week cover, to some depth, knowledge from a particular field. The last half hour of the class is used to complete the science or design activity for that week of mentoring. Despite its conceptually simple nature, this segment of the mentoring course is of great importance. All the mentors in BEAM are required to have successfully completed the activities that the mentees have to complete. This way, the students can provide better assistance and guidance both in the conceptual basis of the activity and the actual construction of the project.

The mentors are also required to complete a final project to pass the course. In the final project, mentors are asked to design, implement, and assess a novel lesson plan. This exercise gives mentors a taste of curriculum planning and allows them to gain a wider range of skills in mentorship. Students are given comprehensive guidelines for the project including sections on: teaching plan, scientific background, method of topic introduction, list of demonstrations, main activity, closing discussion, and a summarizing worksheet. The guidelines also include a bill of materials, learning styles assessment, and references. A five minute pitch of the lesson plan and a formal presentation (given after teaching) are the deliverables. This project gives the mentors a larger role in the content and leadership of outreach and also allows BEAM to be sustainable and develop an ever-increasing pool of lesson plans.

### **Leadership Structure**

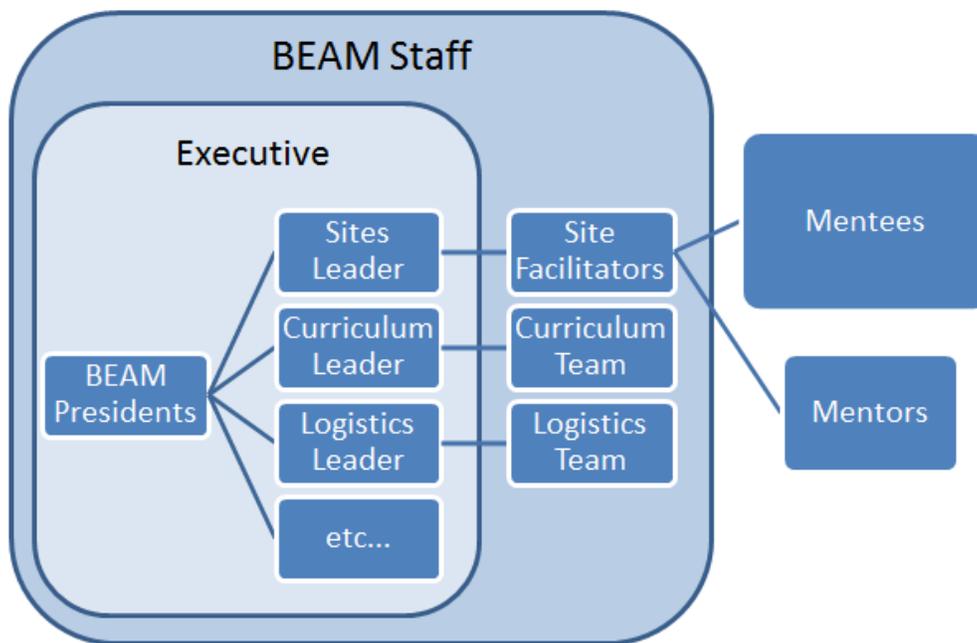
BEAM is structured like a small business. We pulled many ideas from our past internship and research experiences. BEAM members are encouraged to be leaders from the very beginning. The system is designed to allow incoming mentors to slowly attain more leadership and responsibilities. Mentors and mentees are at the base of the leadership structure. They are lead by

the BEAM staff, which is sub-sectioned according to roles (i.e. site facilitators, curriculum team, etc). The leadership structure is mapped out in Figure 2.

By the third week of mentoring, site facilitators encourage mentors to take the lead and facilitate the lesson themselves. This gives the mentors practice before designing and teaching their own lesson plan as part of their final project. Mentors enrolled in the course are given the responsibility to assess the learning objectives of their own mentees in their final project. Returning mentors are encouraged to become staff, adding to their responsibilities and giving them more practical leadership experience.

Mentors also have the option of becoming staff in one of the other BEAM teams: Curriculum, Sites, Finance, Marketing, Logistics, Internal Affairs and Web Development. Each team is lead by a vice president, who works with two co-presidents in the executive team.

This leadership structure has been developed to provide longevity to BEAM. By assigning mentors to defined teams and heading each team with an experienced leader, the structure ensures that each job is passed on to capable successors. Additionally, the presidents have overlapping terms to make sure that there is always an experienced president on staff. This new system has given us the flexibility to grow as an organization by increasing the size of the teams and by creating new teams as new needs arise.



**Figure 2: BEAM staff organization**

## **Assessment**

The performance of the organization is assessed by three criteria: (1) development of leadership skills in our mentors (2) development of our mentees and (3) changes in our mentees' attitudes towards engineering. Development of assessment methods was guided by our learning objectives.

One of the goals of BEAM is to increase participation in engineering and engineering programs by minorities and girls. To ensure this, surveys were given out to determine the demographics of our mentors and mentees.

We developed two tools to assess the learning objectives of our mentors. First, in order to assess the self-development of the mentors, two identical surveys were given at the beginning and end of the semester. Mentors were asked to rate 11 personal skills such as leadership and creativity on a scale from 1 (low) to 5 (high). In the final survey, mentors were also asked to retrospectively rate their competency at the beginning of the semester.

In addition, mentors were required to blog about each weekly mentoring session. The purpose of the blog is to aid reflection and help mentors verbalize their mentoring experiences. At the start of each mentoring class, mentors are encouraged to discuss strategies that worked or failed at their sites the previous week. Feedback from the weekly blogs is shared and analyzed together.

One form of assessment used to evaluate the primary school mentees is the Draw an Engineer Test, an adapted form of the Draw a Scientist Test<sup>2</sup> (DAST). The test was administered before and after the 10 week program to gauge the ideas and preconceptions about science and engineering held by our mentees. By comparing the results and identifying key themes and trends in the students' drawings, we were able to qualitatively judge the impact our outreach program had on attitudes about technical careers.

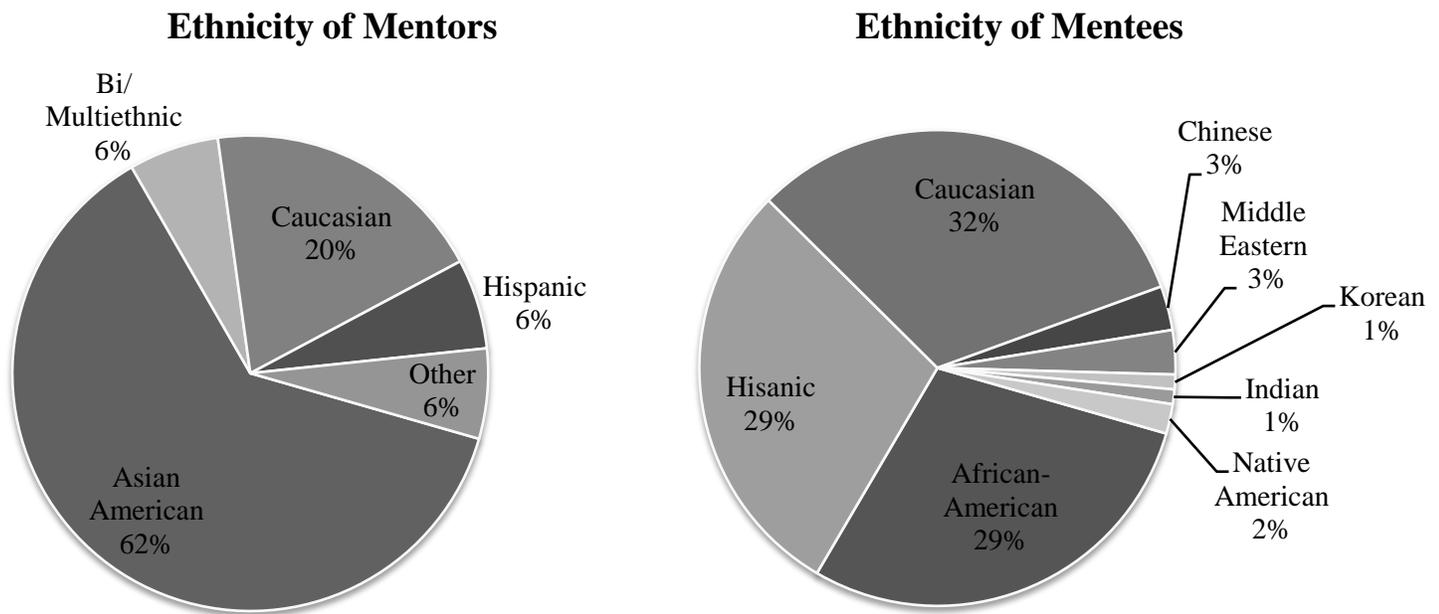
Mentors also developed their own forms of assessment and reported the results as part of their final project.

## **Results**

The achievement of mentor and mentee learning objectives is used to quantify the success of the BEAM program. The various assessment activities (mentor survey, draw a scientist test, final projects, etc) implemented provided a vehicle for qualitative and quantitative outcomes. This section will outline and describe the outcomes for the program via the learning objectives and assessment activities.

## **Demographics**

BEAM is committed to increasing the diversity of the student population it serves. BEAM strives to recruit a diverse team of mentors and reach a diverse group of children. A breakdown mentor and mentee demographics are found in Figure 3.



**Figure 3: Ethnicity data for mentors and mentees.**

### Mentor Self-Assessment Surveys

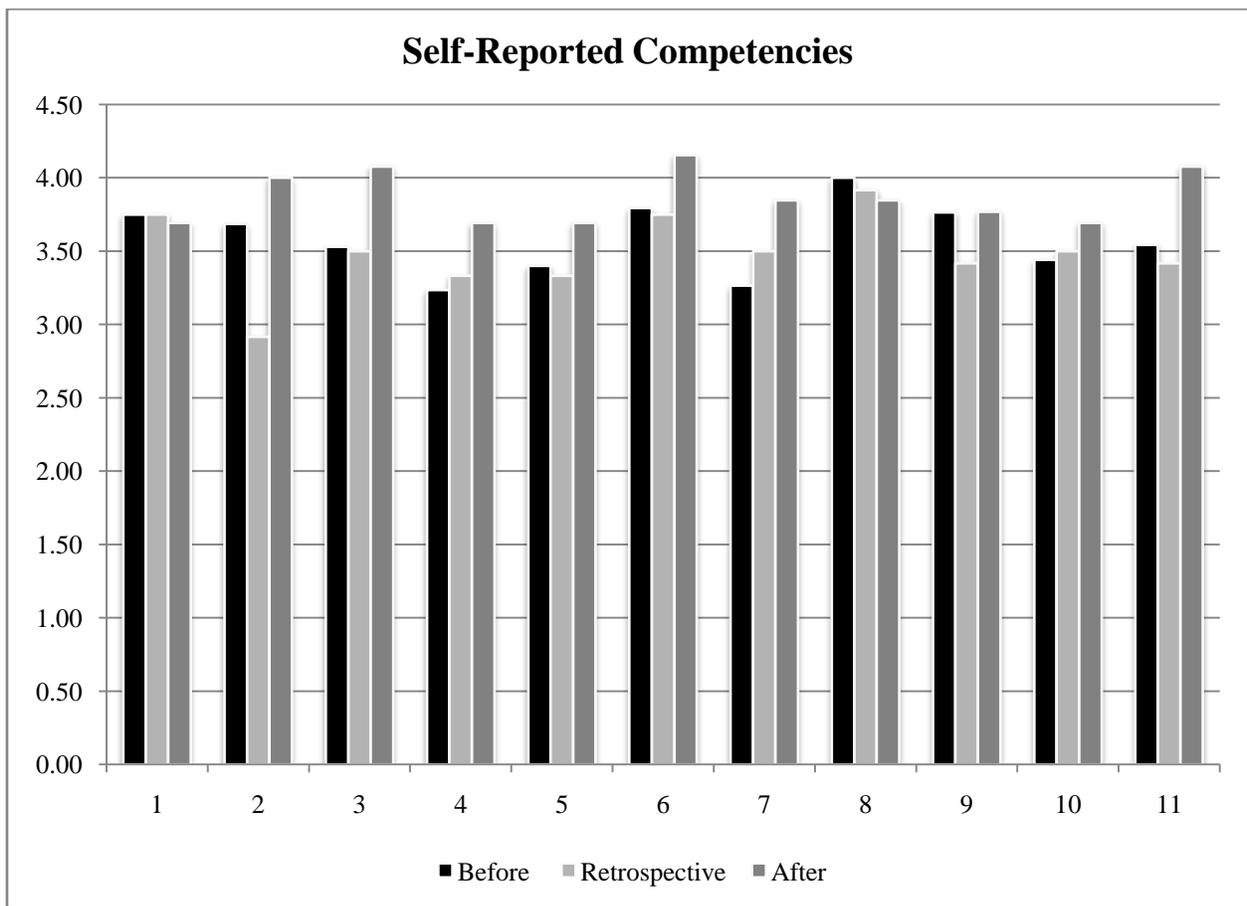
Mentors were asked to rate their competencies through two self-assessment surveys. On average, the mentors reported improvements in all the learning objectives over the course of the semester (Figure 4). Table 3 shows the questions asked. Twenty-six mentors responded to the survey. Comparing retrospective responses to "after" responses, the largest improvements were in "exhibit creativity and practical ingenuity," "dynamic/agile/resilient/flexible," and "ability to recognize the global economic, environmental, and societal impact of engineering design and analysis." In general, these trends are repeated comparing the "before" responses to the "after" responses.

Responses to question 2 indicate that mentors were overconfident about their creative skills before participation in BEAM. This also indicates that mentors felt that they improved more than they had anticipated. Responses to question 7 indicate that mentors felt they had underestimated their leadership skills at the beginning of the semester. The "after" responses show that mentors gained more confidence as leaders.

Responses to questions 1 and 8 seem to indicate that mentors felt BEAM had little impact on their analytical skills or standards of professional conduct. The response to question 8 could have stemmed from the fact that it was poorly worded and incorporated two different concepts (ethics and professionalism) into one question. A way to improve this issue would be to ask two separate questions.

1	Possess strong analytical skills.
2	Exhibit creativity and practical ingenuity.
3	Ability to develop designs that meet needs, constraints and objectives.
4	Ability to identify, formulate, and solve engineering problems.
5	Good communication skills with multiple stakeholders.
6	Good team skills with people from diverse backgrounds and disciplines.
7	Leadership and management skills.
8	High ethical standards and a strong sense of professionalism.
9	Dynamic/agile/resilient/flexible.
10	Ability to learn and use the techniques and tools used in engineering practice.
11	Ability to recognize the global, economic, environmental, and societal impact of engineering design and analysis.

**Table 3: Mentor-Self Assessment Skill Areas**



**Figure 4: Average confidence rating from self assessment surveys. Questions are found in Table Y. "Before" questions were from the beginning of semester survey. "After" and "retrospective" questions were from end of semester self assessment.**

### Mentee Draw an Engineer Test

The Draw an Engineer Test was very successful in tracking changes in mentees' attitudes to and preconceptions towards engineering throughout from the beginning to the end of the semester. Initially, mentees had little idea what engineers actually did, and consequently drew pictures of the stereotypical construction worker, auto mechanic, and mad scientist. By the end of the semester, although some stereotypical elements remained, the responses from the students were more diverse, consisting of astronauts, robotics engineers, and chemists. On one occasion the mentee drew himself planning a blueprint, showing that he believed engineering is not limited to adults, but can be done by children as well.

Many of the ideas of our mentees in the "after" activity were directly related to our lessons and activities. This indicates that our lessons had a large impact on their perceptions of engineering and science, but also that they are not being exposed to these ideas elsewhere. There is great potential to introduce students to new fields and applications of engineering in their community.



**Figure 5: DAET "Before". Note the stereotypical presentations of the engineer and scientist.**



**Figure 6: DAET "After". One student draws a “scientist” closer to her phenotype. Another draws a "car of the future."**

### **Final Projects**

The final presentations were given at a semi-formal event called the BEAM Mini-Conference. It was clear that the additional effort required for this final project and presentation created a sense of pride and ownership in the mentors. It also helped them to take ownership of the semester long relationships they developed with their mentees.

Moreover, mentors developed effective and novel assessment tools for their mentees. Mentors noted that written tests were counterproductive to engaging mentee participation. One mentor group created a simple worksheet where mentees were asked to match the lesson plan to the scientific/engineering concept that it dealt with. 79 percent of the mentees had zero wrong answers and 21 percent of them had one wrong answer.

All project groups gave an evaluation of the entire BEAM semester at their sites, explaining the successful methods, the areas of improvement, and recommendations for improvements. The final project provides an effective means of assessing mentors and gathers new ideas for improving the program.

Lastly, many of the final projects also emphasized iteration of the design process, which is rarely done in classes today. This demonstrates that the mentors engaged in the top four tiers of Bloom's Taxonomy (Apply, Analyze, Evaluate, and Create). The process of making lesson plans forced students to utilize these upper levels because it encouraged them to understand the concepts, evaluate what was important, and teach the material in a novel way. While mentors were not actively exposed to Bloom's Taxonomy, the principles that govern it were incorporated in the thought processes of the mentors.

## **Summary and Future Work**

BEAM is unique amongst engineering outreach efforts in that it is designed, implemented, and led entirely by students. Our mission has grown to encompass leadership development as an equally important goal next to mentorship. Our leadership structure encourages mentors to take initiative and responsibility early on.

BEAM is a data-driven organization. Every activity is coupled with a novel assessment tool to gauge its impact. An evaluation by our mentors showed that they benefited personally from taking the class. Mentors particularly cited their ability to lead, think creatively, and recognize the broader impact of engineering. Our mentees showed notable changes in their conceptions about engineering and science, made visible through the Draw An Engineer Test.

### **Future Work**

In the near future, BEAM intends to collect more quantitative data from both the mentors and mentees through surveys and worksheets. Additionally, we hope to obtain data from outside sources such as the parents of mentees and schools. This will better enable BEAM to determine where its program excels and where it can improve.

Every year, new partnerships are being formed with new schools and other universities, extending BEAM's impact outside our local community. One of the goals for the future is to make all the lesson plans, worksheets, and other resources publicly available. Currently, in order to achieve this, a central BEAM website is used to archive all the lesson plans from the past. Work is already being done to further improve the searchability of the lesson plans as well as to collect comments and criticism from other teachers on aspects of the lesson plan that worked particularly well or could be improved. By effectively packaging the BEAM model and resources into one location, we hope to facilitate BEAM's growth to other engineering schools throughout the country.

Another goal of BEAM is to integrate the program into the university's core engineering program. As supported by our assessments, BEAM improves the mentors' problem solving abilities and gives them the chance to teach one another, thus reinforcing theoretical class material. In a further effort to integrate engineering and outreach, mentors will also work with faculty to design their lesson plans for the final project, incorporating cutting-edge research projects into elementary lessons. Another possible effort is to design a separate mentoring and teaching class for upper division BEAM students that can serve as a thesis course. Students taking this course would design and test novel lesson plans and teaching methods to help shape future BEAM efforts.

### **Acknowledgements**

We would like to thank our advisor for supporting the organization and getting it started. We would also like to thank our mentoring professors who have dedicated their time and expertise in

teaching us how to teach effectively, the after school directors for providing us with a place to teach, as well as our community partners for providing us with funds, materials, and a location for our mentor training workshop. And finally, we would like to thank the rest of the BEAM staff for devoting their time efforts to make BEAM a success.

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