MENTORING TO INCREASE INTEREST IN THE STUDY OF ENGINEERING IN UNDERREPRESENTED HIGH-SCHOOL STUDENTS VIA A DESIGN MECHANISM

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Abstract

The DREAM Program (Designing with Rice Engineers – Achievement through Mentorship) was developed to encourage underrepresented minority high school students to pursue college studies in STEM fields, particularly engineering. The DREAM Program has taken shape over the last three years at Austin High School (AHS). Through this program Rice University undergraduate engineering student mentor AHS students throughout the academic year. The mechanism for establishing the mentor/mentee relationship is an open-ended design competition. Two to three AHS students (mentees) form a team with a Rice University group leader (mentor). One day a week, after school, the team meets to solve a design challenge. After 5-7 weeks of design, testing and iteration, AHS students are then compete with their designs on the Rice University campus. AHS is a public school (Houston Independent School District – HISD) of approximately 1850 students, of which approximately 95% are Hispanic and 3% are African American, with 86% of the student body receiving reduced price or free lunch.

Assessment of DREAM is carried out through several mechanisms, including Perception and Environment Surveys (P.E.S.), Intuition Inventories (I.I.) and Physics Concepts Inventories (P.C.I.). P.E.S. provide information related to the college application and admission processes, and introduce concepts such as long-term earning potential. Data is collected from both DREAM mentees and a control group (over 300 AHS students in 2007-2008). The invited mentees are further divided into i) those who consistently participated (over 70% attendance), ii) those who did not participate, and iii) those with inconsistent participation. Attendance at DREAM Day at Rice University is also factored into the analysis. Most notable, surveys completed by DREAM mentees indicate the increased value they place on math classes. Measured initially in the fall of 2007 before DREAM began, only 24% recognized the importance of math classes for going on to study high earning potential fields such as engineering. Most recently in November 2008, nearly 78% saw math as important to their future careers. Results from inventories are similarly positive. In response to the fundamental question about gravitational acceleration on the spring 2008 Intuition Inventory, initially only 44% of mentees answered correctly. After completing the program and DREAM Day at Rice University, 83% of mentees answered this question correctly. In fall 2008, correct answers to the fundamental buoyancy question on the Intuition Inventory increased from 38% to 100%, before and after the program.

Other goals of DREAM include: encouraging students to take as many math and science courses as possible in high school, informing students of the career paths and earning potential associated with obtaining an engineering degree, providing assistance with college applications, and offering a consistent and supportive presence. In addition to providing a structured mentorship for AHS students, there are also significant benefits to Rice University mentors. Mentors enhance their leadership skills and hands-on engineering problem solving, improve their communication skills, and often are introduced to new cultural and socioeconomic experiences. Several mentors have cited outreach through DREAM as broader impacts in successful fellowship proposals.
**Introduction**

Underrepresentation continues to be a widespread problem in Science, Technology, Engineering and Mathematics (STEM) fields, and the statistics are particularly alarming in engineering. In the year 2000, the U.S. Census Bureau reported that 12.3% of the U.S. population was African American and 12.5% was Hispanic or Latino [1]. However, only 11% of baccalaureate degrees in engineering were conferred upon representatives from these two groups combined in 2006 [2]. When considered in light of the fact that respectively, 31% and 35% of the members of these populations are under 18 years of age, there is both cause for concern and hope [3,4]. The worry is that, if left unaddressed, the percentage of underrepresented minorities in engineering will likely decrease even further below the current precarious levels. However, with significant and meaningful outreach efforts, these underrepresented groups offer great potential to bolster the aging engineering U.S. workforce [5]. Also largely underrepresented, women made up only 19.3% of engineering bachelor of science degrees in 2006, the lowest percentage since 1998 [2,6]. This figure highlights a further need for increased mentoring of women in engineering.

DREAM has been developed to address underrepresentation in engineering. The program follows the requirements for successful outreach as described by a recent study at Oak Ridge National Lab, including beginning with an assessment that involves students and teachers, building partnerships, incorporating college students, securing funding, making regular evaluations, and publishing results [7]. DREAM (Designing with Rice Engineers – Achievement through Mentorship) couples small teams of two to three high school mentees with an undergraduate mentor to collaborate to solve a design challenge. Groups meet at least once a week for 5-7 weeks, allowing sufficient time for the mentoring relationship to form naturally. Physics concepts and scientific reasoning skills are introduced and reinforced. Teams are able to design, test and refine their solutions before the final competition. Therefore, mentees are exposed to the entire hands-on components of the engineering design process, from initial brainstorming to testing and redesign and finally prototype development. In spring 2009, written reports and oral presentations will also be included in the program. DREAM also places a high level of importance on changing perceptions about engineering, and the affordability of a college education, and introduces the concepts of long-term career planning and earning potential.

DREAM also provides significant growth opportunities for the undergraduate mentors. DREAM mentors display improved leadership and communication skills, as found in other experiential learning programs such as EPICS [8] and SLICE [9]. Also similar to these programs, undergraduates from underrepresented groups are disproportionately attracted to becoming DREAM mentors. For example, in fall 2008, of the 27 mentors, 10 were women, of which 9 were engineering majors. Furthermore, 13 of the 27 mentors were from underrepresented minority groups, and 12 of these mentors are majoring in engineering. Mentors do not receive pay or credit for their service hours. In fall 2008 alone, mentors volunteered over 200 hours with AHS mentees. This amounted to 500 contact hours with mentees, consistent with the target ratio of one mentor working with two to three mentees.

The remainder of this paper is broken up as follows. First the socioeconomic and ethnic backgrounds of the mentees is introduced. Then the DREAM program is described in sufficient detail to provide a foundation for the assessment section, which follows. The paper concludes
with a brief description of the future work and conclusions thus far. Samples of the competition rules, surveys and inventories are included in the appendices.

**Mentee Backgrounds**

The DREAM program focuses mentoring efforts on inner-city, socioeconomically disadvantaged high school students, from groups underrepresented in STEM fields. The college application process and financial aid are important components given the background of the mentees. Also crucial is demonstrating the long-term earning potential of attaining an engineering degree, in particular compared to entering the job market with a high school diploma.

**Overview of Austin High School Students**

The DREAM program originated at Stephen F. Austin High School where the authors had already developed collaborations with Rice University through tutoring in math and science and assistance with science fair projects. Austin High School (AHS) is a Title I school (as defined by the United States Elementary and Secondary Education Act, for the purpose of distributing funding to schools and school districts with a high percentage of students from low-income families) in the Houston Independent School District [10]. AHS is located in the largely Hispanic Second Ward of the city.

In the 2007-2008 school year the total enrollment was 1,895 students with a breakdown of 48% female and 52% male. The majority of the student body is Hispanic, with only a total of 5% being any other ethnicity [11]. According to the 2008 Texas Education Agency Report one of the components that qualifies a student as economically disadvantaged is if “he or she is eligible for free or reduced-priced meals under the National School Lunch and Child Nutrition Program” [12]; in the 2007-2008 school year, 90% of AHS students were eligible for free or reduced lunch. Also, of the AHS 11th graders who took the Texas state standardized test (Texas Assessment of Knowledge and Skills - TAKS), 40% were considered economically disadvantaged [12].

Academic challenges at AHS are represented in many statistics. For example, recently more than 70% of enrolled students were considered at risk, with a 6% drop-out rate. Less than 50% of seniors take the SAT Reasoning Test. Of those taking the SAT, the Math Average is 441, the Verbal Average is 409, and the Writing Average is 401, as compared to the state averages of 515 in Math, 502 in Reading, and 494 in Writing [13].

**Overview of DREAM Mentees**

The DREAM program recruits mentees in several ways at AHS. Teachers are asked to recommend students, and mentees from previous semesters are asked to invite their friends. The program strives to mix high achieving students with those who are struggling, in an attempt to raise the success of both groups. No willing participant at AHS is turned away, unless they display a lack of commitment over several weeks.
Tables 1 and 2 summarize the grade, gender and ethnicity make-up of the DREAM mentees for the first three implementations of the program at AHS, as collected through use of the Perception and Environment Survey (P.E.S.), an example of which can be found in the first page of the appendices. The high percentage of Hispanic mentees in the program reflects the school demographics. In the most recent data collected (in November 2008 at DREAM Day at Rice University) 18.5% of the students spoke primarily Spanish at home, while 55.5% spoke both Spanish and English. Only 22.2% spoke primarily English at home.

Of particular interest to the purposes of this program are the number of mentees who plan on going to college. In the control data in September of 2007, only 3.5% of students said they did not plan to go to college. All of the DREAM mentees surveyed from September 2007 through November 2008 have stated that they plan to go to college. This data does not consistent with the dropout rate of the school or the low percentage of seniors taking the SAT exam. This indicates a lack of understanding among AHS students about the requirements and competition for college admission. This is a misconception that DREAM seeks to undo.

**DREAM Program**

At AHS, DREAM groups undergraduate engineering students with two to three high school mentees, forming a team to solve a design challenge. Due to significant interest in DREAM, many mentees come more than their assigned single day per week. As a result, the contact hours are approximately 2.5 mentee hours per mentor hour, although the actual ratio of mentees to mentors at AHS is two-to-one.

**Mechanism**

The main purpose of the DREAM program is to find an optimal mechanism for the interaction between economically disadvantaged high school students and college role models in the STEM career paths. The founding members of the DREAM program included two underrepresented engineering undergraduates, who understood the importance of role models in their own STEM careers, and valued participation in outreach activities to benefit the community. Therefore the
undergraduate participants, referred to as mentors, were asked to volunteer freely their hours to accomplish this mentoring program.

Unique to the DREAM project mentoring mechanism is its design competition framework. The design challenge each semester has provided the program structure that promotes a focused objective and keeps the high school students, otherwise referred to as mentees, motivated. During the four to seven weeks that the mentees brainstorm and trouble-shoot the design solutions, the mentors try to bridge the gap between the engineering concepts and the applications of those concepts. Most importantly, throughout the design process the mentees form comfortable bonds with their mentors. This allows for casual conversations which lead into more significant exchanges of information. Mentors share their experiences in the college application process and in their academic development at Rice University. Here is where the DREAM project fulfills it goal and the mentors try to elaborate on what the students should do to prepare themselves to be competitive candidates in the college application process. Interestingly, working in teams and interacting on a weekly basis in the design process allows the mentees to gain confidence in their mentors. Questions about college come spontaneously and unabashedly, allowing for the best natural interaction between the mentees and their mentors.

**Implementation of DREAM over a Semester**

Since the fall semester of 2007, the DREAM project has been structured in the following way:

*Before the program begins:*
1. High school students from Stephen F. Austin High School are recommended by their teachers to be in the program, or are recruited by other mentees
2. The selected mentees are sent letters from the DREAM project explaining the program and inviting them to attend a special introduction day.
3. The introduction is held a week later at the high school campus. The design challenge is revealed and the students are asked to fill out questionnaires. These questionnaires collect basic data on the students and determine which days they are available after school to participate in the program.
4. The mentees are assigned to one afternoon a week for the program and informed of their day.
5. Simultaneously, mentors from Rice University are recruited and asked for their preference for participation days. Mentors are also asked if they are able and willing to provide transportation for other mentors on their same day.
6. The mentors are assigned one day a week to participate in the program. A driving mentor is always assigned to every group so that each day there is a guaranteed group of university students at the high school campus.

*During the program:*
7. The mentors and mentees are given the design challenge document, the scoring methodology document, and a box of pre-prepared materials to begin the design process.
8. Groups of two to three mentees to one mentor go through the design process which includes brainstorming, building, testing, and trouble-shooting.
9. Mentees are also given physics inventories specific to the concepts used in the design challenge. These are collected and recorded.
10. This process lasts between five to seven weeks depending on the scheduled final competition date.

11. On the final competition date all mentees are invited to the Rice University campus to compete for first, second and third place. All scoring methodology is previously determined and given to the mentees at the beginning of the design process as mentioned above.

12. A full day on campus is scheduled for the mentees with tours, presentations, lectures and meals on the competition date. The mentors participate in all activities with the mentees on this day.

13. At the end of the competition mentees are given the same questionnaires and physics inventories as at the beginning of the program. This data is collected and recorded.

After the competition

14. Mentors are thanked with a fun gathering after the semester has come to a close.

15. All mentee data is analyzed and stored.

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**Fall 2007 Design Competition**

The fall 2007 DREAM design program consisted of six weeks of design process at Stephen F. Austin High School. The primary objective was to build a device for an object to travel exactly 120 seconds from an elevated position to ground level, and arrive “just-in time”. The elevated position had to be between 50 and 150 cm (19.685 – 59.055 in) above the ground level (ground level was a table top surface). The travel path of the object had to reside within a virtual space of 150 x 150 X 150 cm (59.1 x 59.1 x 59.1 in). Movement up, down, left, right, spiral, free fall, etc. was acceptable within the limits of the virtual space. Only the first contact of the object with the ground level within the virtual space determined the end of travel time. The list of materials included 8.5 x 11 inch printing paper, scotch tape, rubber bands, string, pencils, pens, paperclips, magnets, binder clips, tacks, a balloon, an eraser, and a plastic ruler. A table tennis ball was used as the object for travel. On the day of the competition the groups had a maximum of one hour to build their completed design and then three tries to demonstrate it. A total of 25 mentees and 13 mentors participated consistently in the design process, and 17 mentees attended the final competition on November 10th, 2007. The detailed design document which includes competition rules, materials list and scoring is included in the final appendix.

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**Spring 2008 Design Competition**

The spring 2008 DREAM design program consisted of five weeks of design process at Stephen F. Austin High School. The challenge was to be able to drop an egg from the highest height possible and prevent it from breaking upon impact with the ground.
The groups were provided a shoebox full of materials such as 8.5 x 11 inch printing paper, a tennis ball, a balloon, scotch tape, foam wedges, cotton pads, bubble wrap, sponges, rubber bands, and Ziploc bags. On the day of the competition the teams had a maximum of forty-five minutes to completely build their device. Their design were tested from heights varying from 3 feet to 30 feet and prizes for the first three overall scores as well as the most efficient and most innovative designs were given at the end of the day. A total of 23 mentees and 13 mentors participated consistently in the design process, and 12 mentees attended the final competition on February 23rd, 2008. The drop-off in mentee participation was attributed to a lack of promotion of the project, and conflicts with standardized testing and competition with after-school jobs.

**Fall 2008 Design Competition**

The fall 2008 DREAM design program consisted of seven weeks of design process at Stephen F. Austin High School. The objective of this program was to be able to float cargo (steel ball bearings) and keep it dry in a Floatation Device. The teams were provided a box of materials such as 8.5 x 11 inch printing paper, scotch tape, plastic drinking straws, cotton pads, sponges, rubber bands, binder clips, and a small plastic plate. On the day of the competition the teams had a maximum of forty-five minutes to build their device. The devices were tested in the Rice University pool. During testing the groups were allowed to begin with any amount of weight, and add more mass in any increment they desired. The device had to remain afloat for at least 30 seconds after each addition of weight. Prizes were awarded to the teams with the four highest overall scores, a most innovative design, and a most stable design at the end of the
competition. A total of 34 mentees and 27 mentors participated consistently in the design process, and 28 mentees attended the final competition on November 21\textsuperscript{st}, 2008.

Assessment

Perception and Environment Surveys

The main goal of this program is to encourage the mentees to think about college and consider studies and careers in engineering disciplines. The following data is taken from the mentee questionnaires (P.E.S.), and indicates significant improvements in understanding of what engineers actually do in their careers.

While there was little progression to be seen in the students’ intentions to go to college (considering the surprisingly high number of initial positive responses to the question “Do you plan on going college?”), there was a notable increase in the students’ knowledge of “What an engineer does” from the initial September 2007 survey before DREAM began to the most recent survey of DREAM mentees. This increase in the level of understanding is demonstrated in Table 3 below, where all results except that labeled “control” are from responses by DREAM mentees. The free response answers to this question were coded by understanding levels from “none” to “exceptional”. A typical response coded “None” means the student responded “I don’t know”. “Little” understanding would be indicated by responses such as “builds things”. “Basic” understanding would be described by a response such as “Builds, makes, or fixes things”. Use of the word “invents” or “designs” indicates good understanding. “Exceptional” understanding would be indicated by a response such as “Uses math and science to solve problems.”

Table 3. Control and mentee understanding based on responses to the survey question “What do you think an engineer does?”, question 16 on the sample P.E.S. included in the appendices.

<table>
<thead>
<tr>
<th>Date</th>
<th>No Answer</th>
<th>None</th>
<th>Little</th>
<th>Basic</th>
<th>Good</th>
<th>Exceptional</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 2007 control</td>
<td>20.4%</td>
<td>22.4%</td>
<td>40.3%</td>
<td>14.4%</td>
<td>2.5%</td>
<td>0%</td>
</tr>
<tr>
<td>September 2007</td>
<td>0%</td>
<td>13.8%</td>
<td>41.4%</td>
<td>24.1%</td>
<td>20.7%</td>
<td>0%</td>
</tr>
<tr>
<td>January 2008</td>
<td>0%</td>
<td>5.6%</td>
<td>16.7%</td>
<td>50%</td>
<td>22.2%</td>
<td>5.6%</td>
</tr>
<tr>
<td>September 2008</td>
<td>0%</td>
<td>14.3%</td>
<td>31.0%</td>
<td>26.2%</td>
<td>28.6%</td>
<td>0%</td>
</tr>
<tr>
<td>November 2008</td>
<td>3.7%</td>
<td>7.4%</td>
<td>14.8%</td>
<td>29.6%</td>
<td>33.3%</td>
<td>11.1%</td>
</tr>
</tbody>
</table>

The control and mentees were also asked about the highest level of education obtained by their parents. Another trend has been uncovered from this question. As expected, an exceptionally high number of mentees had parents who had only a middle school or lower level of education (in November of 2008 the percentages being 44% and 37% for mother and father, respectively). However, of the mentees tracked over three semesters, eight changed from either not answering or circling “unknown” to marking a level of education. While not a large number, this does represent approximately 25% of the mentees who have participate in DREAM for several semesters. This indicates one of two things. Either DREAM is encouraging these mentees to explore their parents’ educational backgrounds, or the mentees have become sufficiently trusting
that they are willing to answer this question honestly. Either is a positive for the goals of the program, and new surveys are being developed to try to discern the reason behind this increase.

Another interesting and important statistic is an apparent fear or dislike the mentees display for taking out student loans to pay for college. In January of 2008 the survey began asking the students how they planned on paying for college if they chose to go. The results are given in Table 4.

<table>
<thead>
<tr>
<th>Date</th>
<th>Parents Alone</th>
<th>Scholarships Alone</th>
<th>Loans Alone</th>
<th>Work-Study Alone</th>
<th>Multiple answers, Parents Included</th>
<th>Multiple answers, without Parents</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2008</td>
<td>5.6%</td>
<td>33.3%</td>
<td>0%</td>
<td>0%</td>
<td>38.9%</td>
<td>16.7%</td>
</tr>
<tr>
<td>September 2008</td>
<td>4.8%</td>
<td>26.2%</td>
<td>0%</td>
<td>9.5%</td>
<td>19.0%</td>
<td>40.5%</td>
</tr>
<tr>
<td>November 2008</td>
<td>0%</td>
<td>18.5%</td>
<td>0%</td>
<td>11.1%</td>
<td>29.6%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Note the complete neglect of considering loans as a sole means of paying for college.

There is also a promising trend in the number of students who see a strong correlation between the amount of Math courses they take and amount of money they can make. In response to the question: “Do you think how many math courses you take influences how much money you can make?” the following responses have been recorded.

<table>
<thead>
<tr>
<th>Date</th>
<th>Not</th>
<th>Hardly</th>
<th>A little</th>
<th>A lot</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 2007</td>
<td>13.8%</td>
<td>6.9%</td>
<td>55.2%</td>
<td>24.1%</td>
</tr>
<tr>
<td>January 2008</td>
<td>0%</td>
<td>0%</td>
<td>55.6%</td>
<td>44.4%</td>
</tr>
<tr>
<td>September 2008</td>
<td>4.8%</td>
<td>2.4%</td>
<td>33.3%</td>
<td>59.5%</td>
</tr>
<tr>
<td>November 2008</td>
<td>0%</td>
<td>4%</td>
<td>14.8%</td>
<td>77.8%</td>
</tr>
</tbody>
</table>

The greatest difference can be seen in the great increase in the number of students who saw a high correlation (“A lot”) between math courses and income potential. This steady increase is most likely attributable to the hours of mentoring provide through DREAM.

**Inventories**

The most significant and easily measurable outcomes of DREAM have been observed through responses on Intuition Inventories and Physics Concepts Inventories. Intuition Inventories (I.I.) measure mentee understanding of physical mechanisms, without strictly requiring mathematics or algebraic notation. Physics Concepts Inventories (P.C.I.) add these mathematical and symbolic components. Samples of these from spring and fall of 2008 are included in the
appendices. The percentage of correct answers went up dramatically on most questions, as measured before the program and at the end of DREAM Day, each semester.

The spring 2008 I.I. focused on gravitational acceleration, decomposition of motion, and air resistance, and accompanied the egg-drop competition. Correct responses on multiple choice questions 1 and 2 increased from 44% and 11% to 83% and 58%, respectively. The free response question 3 saw a slight increase from 11% to 25% correct answers. Partially correct answers to this question also increased slightly from 39% to 42%. The results of question number 3 were not statistically significant overall. Only the concepts in question 1 were discussed specifically during DREAM Day. To better evaluate if this improvement is short-term or long-term, the spring 2009 DREAM project has also been designed to test decomposition of motion and gravitational acceleration. These results will be presented in a future paper. The initial I.I. and P.C.I. will help determine if the mentees truly have learned and retained this concept, or if the data is skewed by “teaching to the test”.

The spring 2008 P.C.I. focused on potential and kinetic energy concepts. Significant increases were observed in the number of correct responses to both the multiple choice component and short answer segments of question 1. On the multiple choice component of question 1, correct responses increased from 61% to 100% before and after DREAM. On the free response components of question 1, initially no students were able to correctly formulate the potential or kinetic energies, while after DREAM Day, 58% correctly answered these questions. The concepts in question 2 of the spring 2008 P.C.I. was not discussed. Surprisingly, only one mentee answered this question correctly initially, and none answered correctly after DREAM Day. This highlights the importance of both deep and broad discussions about such physics concepts to promote true understanding. As a result of this finding, in spring 2009 DREAM has started to incorporate mini-lectures during the mentoring. The final question on the spring 2008 P.C.I. was answered correctly by 50% of the mentees initially, with one mentee receiving partial credit. After DREAM, 75% answered correctly and 25% received partial credit, indicating some level of understanding in all mentees. Equally significant, the percentage of time that this question was left unanswered decreased from nearly 28% to 0%. This indicates either increased confidence in the mentees, or a willingness of the mentees to take risks without fear of feeling foolish, or both. Either way, this is a positive outcome for DREAM.

The fall 2008 I.I. focused on buoyancy and stability concepts, and accompanied the floatation device competition. Correct responses to multiple choice question 1 increased dramatically from less than 35% initially to 100% after DREAM Day. Question 2 did not show improvement, as most (~85%) were able to answer this question correctly from the beginning. This percentage was unchanged after DREAM Day. Multiple choice question 3 saw an increase from less than 10% correct responses initially to 56% correct at the end of DREAM Day. Free response question 4, which was not specifically discussed on DREAM Day, saw a slight decrease in wrong answers from 74% to 67%, with approximately even distributions of correct and partially correct answers.

The fall 2008 P.C.I. showed that symbolic notation and dimensional analysis still proved difficult for the mentees. Initially more than 50% were not able to choose the units on volume. After DREAM Day, nearly 88% answered this correctly. However, more than 80% choose the correct
units for mass initially, and this increased only slightly after DREAM Day. No significant change was observed in question 2. A 10% improvement was found in the multiple choice question 3 after DREAM Day. Again, the number of unanswered short answer questions decreased significantly. Among those taking the P.C.I. initially and after DREAM Day, blank responses decreased from between 73 and 82% to between 17 and 46%, depending on the question. Depending on the question, percentages of correct and incorrect responses increased with this increase in response rate.

This data all indicates that DREAM is effective for explaining physics concepts with hands-on learning, but also highlights the need for increased attention to symbolic notation, units and algebra, where less progress was observed. Also, DREAM mentees are clearly emboldened to take chances in their answers, especially to free response questions. Whether the mentees are more confident in their answers (often independent of the correctness) or are simply more comfortable in the DREAM program cannot be determined, though it is proposed that the latter is more likely.

**Anecdotal Evidence**

Initial anecdotal evidence of the effectiveness of DREAM is starting to emerge. Most significantly, on of the first (and oldest) mentees enrolled in a mechanical engineering degree program at a high ranging engineering university in the fall of 2008 and continues to pursue that degree. Among other advice, this mentee was counseled by a mentor to take calculus before graduating high school. This certainly impacted the readiness of the mentee for a college education in engineering.

Other anecdotal evidence is observed through the questions the mentees ask of the mentors. It is quite common for mentees to ask about college life, careers, difficulty of majors, financial difficulties and other concerns common to all students entering college, but particularly troubling for high school students who will be the first in their families to attend college. These questions tend to increase throughout the semester, and from semester to semester with consistent mentee participation. Future work to quantify this evidence will include observations of mentee/mentor interactions and coding of questions and discussions.

**Impact on Mentees**

Mentees report increased confidence in team management, and high satisfaction from mentoring. These impacts will be quantified in the future through mentor surveys both before and after each semester of DREAM. More significant impacts include citation of service through DREAM in scholarship and fellowship applications. Most notable, two mentors have cited significant outreach in NSF Graduate Research Fellowship Program proposals, and these have been highlighted as positives in reviews of these proposals. One mentor received an NSF fellowship and a second was given honorable mention.

**Future Work**
Recent agreements have been made to include both grades and standardized test scores in the future assessment of DREAM. This will allow for additional comparisons between mentees and their peers who do not participate in DREAM. This should clarify the impact of the DREAM program, and distinguish its benefits from those of the education all AHS students are receiving. Many of the concepts discussed in DREAM are covered in Texas state standardized testing, and a comparison of scores in these areas will also be enlightening. Furthermore, validity and reliability testing will be performed on the inventories, to ensure that they are quality measurement tools. Finally, mentor reflection has been added to DREAM. After each session, the mentors will track any discussions they had with their mentees about college, the content, and whether the conversations were initiated by a mentee or mentor. This reflection will allow for a measure of the formation of true mentoring relationships.

In the spring of 2009, DREAM expanded to two additional high schools. At Chavez High School, DREAM is implemented in a classroom rather than after-school setting. This will provide interesting comparisons between implementing a mentoring program in a formal versus informal setting. The classroom setting allows for more effective mini-lectures, which should result in measurable improvements in both I.I. and P.C.I. scores. Also, mentees at Chavez High School document and present their work in design reviews, adding the last component of the design process to the DREAM Program. Finally, because DREAM at CHS occurs in a more controlled setting, the ratio of mentees to mentors can be larger, without jeopardizing control of the classroom. Currently the ratios of mentees to mentors at CHS are between five and six to one. Comparing the results of the mentor reflections should determine if this significantly larger ratio has an effect on the formation of a mentoring relationship.

At KIPP Houston High School, the implementation will be similar to that at AHS in that it will be an after-school activity. Unlike at AHS, after-school Co-Curricular Opportunities are mandatory. Also, the KIPP campus and philosophy will soon provide a mechanism for testing the long-term vision of DREAM – training 11th and 12th graders who have spent two years as mentees to become mentors for middle school students. This helps address the scalability issues inherent in one-on-two or one-on-three mentoring. Also, it allows for mentoring to begin in the critical middle school years, where at-risk students often begin to eliminate the range of futures available to them. At KIPP the ratio is slightly less than four mentees per mentor.

Conclusions

The DREAM program has shown measureable and significant mentoring and educational outcomes. While many underrepresented high school students expect to go to college, few are aware of what is necessary to achieve this goal. The DREAM program provides the mentoring and guidance needed to help make this goal a reality. Also, it has been shown to effectively introduce the idea of a career in engineering, and highlight the importance of taking quality classes such as upper-level mathematics in high school. The strong increase in mentee performance on Intuition and Physics Concepts Inventories indicates the effectiveness of the experiential learning and design activities for explaining physical mechanisms. This also helps reinforce the relevance of classes often viewed as abstract by many high school students.
The DREAM program is sponsored principally by a grant from the Bank of America Charitable Foundation, Inc. DREAM is also sponsored in-part by the Rice-Texas Medical Center Chapter of Sigma Xi, and in-part and in-kind by the Rice University School of Engineering and Rice Recreation Center. DREAM also benefits from an HP Technology for Teaching grant.

Special thanks are due to Tim Johnson of AHS, one of the founding members of DREAM and a tireless supporter Tony Castilleja, and the Houston East End Chamber of Commerce for in-kind support. Most importantly, thanks is due to the more than 50 mentors who have volunteered their time for the DREAM program.

References


**Questionnaire**

January 2009

Name ______________________________________________

<table>
<thead>
<tr>
<th>Current Year (circle one):</th>
<th>Freshman</th>
<th>Sophomore</th>
<th>Junior</th>
<th>Senior</th>
<th>Gender (circle one):</th>
<th>Male / Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Race/Ethnicity: (circle one or more)</th>
<th>African-American/Black</th>
<th>Asian-American</th>
<th>Caucasian/White</th>
<th>Hispanic/Latino</th>
<th>Native American</th>
<th>other _____________</th>
</tr>
</thead>
</table>

1a) What is the primary language you speak at home? ______________

1b) What is the secondary language, if any? ______________

2) What do you plan to do after high school? get a job go to college both

3a) Do you think you can afford college? Yes No

3b) How much do you think a year of college costs? $ ____________

4) If you are going to college, how do you plan to pay for college (circle all that apply)?

parent(s)/guardian(s) scholarships loans work-study/part-time job don’t know

5) What portion of college costs do you think might be covered by financial aid for you (circle one)? all most some none

6a) Do you know what the FAFSA is? Yes No

6b) If Yes, have you ever filled out the FAFSA? Yes No

7) Many universities have “no-loan” policies based on family income. This means, if your parent(s) or guardian(s) make less than a certain amount of money per year, the university will give you a scholarship. How much do you think the “no-loan” family income is at Rice? $ ____________

8) Do you think math courses are important for entering science and engineering? Yes Maybe No

9) How does the number of math courses you take influence how much money you can make in your career?

- a lot
- a little
- hardly at all
- not at all

10) How much math do you plan to take in high school? minimum required to graduate 3 years 4 years

11) How much chemistry do you plan to take in high school? none 1 year 2 years

12) How much physics do you plan to take in high school? none 1 year 2 years

13) How much biology do you plan to take in high school? none 1 year 2 years

14) What are your favorite subjects in school? _____________________________________________________________________

Why? _____________________________________________________________________________________________

15) What are your least favorite subjects in school? _____________________________________________________________________

Why? _____________________________________________________________________________________________

16) What do you think an engineer does? ___________________________________________________________________________

17) What do you think a scientist does? ______________________________________________________________________________

18) What is your best guess at the annual (yearly) salary of an engineering major after graduating college? ______________

19) Parents’ highest education levels (circle one choice for each parent):

<table>
<thead>
<tr>
<th>Mother</th>
<th>Father</th>
</tr>
</thead>
<tbody>
<tr>
<td>middle school or below</td>
<td>middle school or below</td>
</tr>
<tr>
<td>some high school</td>
<td>some high school</td>
</tr>
<tr>
<td>graduated high school</td>
<td>graduated high school</td>
</tr>
<tr>
<td>technical or trade school</td>
<td>technical or trade school</td>
</tr>
<tr>
<td>some college</td>
<td>some college</td>
</tr>
<tr>
<td>graduated college w/ associates degree</td>
<td>graduated college w/ associates degree</td>
</tr>
<tr>
<td>graduated college w/ bachelors degree</td>
<td>graduated college w/ bachelors degree</td>
</tr>
<tr>
<td>higher level college degree</td>
<td>higher level college degree</td>
</tr>
<tr>
<td>unknown</td>
<td>unknown</td>
</tr>
</tbody>
</table>

* We would be grateful if you would answer every question, but you may skip the ones you prefer not to answer.
Please answer the questions as best you can. This may be material you haven’t ever covered in class, so it is ok if you don’t know the answers. This won’t be graded, and your teachers and parents/guardians will never see the results. This is only to see if the DREAM project is effective at introducing new concepts.

1) Two balls are dropped from the same height. They are the same size, but the black one is much more dense (“weighs” more). Which statement is true?

a) the black ball hits the ground first
b) the white ball hits the ground first
c) the balls hit the ground at the same time
d) not enough information

2) Two identical balls start at the same height. Ball A is dropped straight down. At the same time, a second ball (Ball B) is shot from a slingshot horizontally. Which statement is true?

a) ball A hits the ground first
b) ball B hits the ground first
c) the balls hit the ground at the same time
d) not enough information

3) Explain why a piece of paper may take longer to fall than a ball when dropped from the same height.

__________________________________________________________________________________________
Have you taken physics? yes no If yes, for how long? less than 1 year 1 year more

1) Balls C and D have the same mass.

Which ball (C or D) has more potential energy (circle one)?

ball C ball D they have the same potential energy not enough information

What is the potential energy of ball C if it has mass M and is at height H? ____________

What is the kinetic energy of ball D if it has mass M? ____________

2) What has more kinetic energy, a train traveling at 60 mph or a car traveling at 60 mph (circle one)?

train car they have the same kinetic energy not enough information

3) What happens to the potential energy of ball E when it is dropped?

_________________________________________________________
Situation: Three empty containers are shown below. One is white, one is grey and one is striped. They have the same mass, the same volume, and are made of the same material (and same amount of material). When empty, all three containers float in water, as shown.

1) If you start to fill the containers with steel through the hole in the top, adding the same amount to each container, which statement is true (you can assume the containers will not tip over or fill up with water)?

a) the white container sinks first         b) the tall grey container sinks first    c) the striped container sinks first
d) it takes the same amount of steel to sink the containers    e) it takes more steel to sink the tall grey container
f) not enough information

2) When the containers are empty, which is most likely to tip over (which is the least stable)?

a) the white container                   b) the grey container               c) the striped container    d) not enough information

3) When the containers are mostly full, which is the most stable (least likely to tip over)?

a) the white container                   b) the grey container               c) the striped container    d) not enough information

4) Why are boats typically V shaped, rather than rectangular like the containers above?
1) The ball shown has volume V, and mass m.

What are the units on volume V?  
- a) length  
- b) length × length  
- c) grams  
- d) seconds  
- e) length × length × length

What are the units on mass m?  
- a) length  
- b) length × length  
- c) grams  
- d) seconds  
- e) length × length × length

What is the density of the ball?  
density = ________________

2) Two blocks have the same volume. Block A is made of wood, Block B is made of steel. Steel is more dense than wood.

Which statement is true?

- a) Block A has more mass than Block B  
- b) Block B has more mass than Block A  
- c) both blocks have the same mass  
- d) not enough information

If the blocks are cubes with sides of length L, and density D, what is the mass?  
mass = ________________

3) The hulls of two boats are shown below. They are the same size, thickness and shape. The boat on the left is made of steel, the boat on the right of wood, which is less dense than steel. Which statement is true?

- a) the steel boat will sit lower in the water  
- b) the wood boat will sit lower in the water  
- c) both will sit the same depth in the water  
- d) not enough information

What force keeps the boats afloat? ________________  
Which way does this force act? __________

If the water has density D, and the wood boat displaces a volume V of water, write this force in algebraic notation?  
force = ________________
**Competition Rules and Material List**

**NOTE:**
The rules, materials list, and scoring methodology for this competition were taken directly from the Rice Engineering Competition held in February 2007. The Rice competition was a great success overall, and we hope that the DREAM competition will be too. Good luck to all!

**DESCRIPTION:**
The primary objective of the 2007 DREAM Engineering Competition is for an object to travel exactly 120 seconds from an elevated position to ground level, and arrive “Just-in-Time”. The elevated position must be between 50 and 150 cm (19.685 - 59.055 in) above ground level, ground level is a table top surface.

The travel path of the object must reside within a virtual space of 150 x 150 x 150 cm (59.1 x 59.1 x 59.1 in), as shown in Figure 1. Movement up, down, left, right, spiral, free fall, etc. is all acceptable within the limits of the virtual space. Only the first contact of the object with the ground level within this virtual space determines the end of the travel time. Once the object makes first contact with the table top surface, it is acceptable for the object to bounce or roll outside the virtual space.

**TIMELINE:**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 1</td>
<td>Organizational meeting with students at AHS</td>
</tr>
<tr>
<td>Week of October 8-12</td>
<td>First team meetings at AHS – Brainstorming</td>
</tr>
<tr>
<td>Week of October 15-19</td>
<td>Team Meeting – Designing</td>
</tr>
<tr>
<td>Week of October 22-26</td>
<td>Team Meeting – Building</td>
</tr>
<tr>
<td>Week of October 29 – November 2</td>
<td>Team Meeting – Testing</td>
</tr>
<tr>
<td>Week of November 5 – November 9</td>
<td>Team Meeting – Finalize Design</td>
</tr>
<tr>
<td>November 10</td>
<td>DREAM Competition at Rice</td>
</tr>
</tbody>
</table>

**Start of the Competition.**
The start of the competition is at your first Team Meeting during the week of October 8-12, 2007. Mentors will bring copies of the Competition Rules, Materials List, and Scoring Methodology documents as well as a set of approved building materials (provided by DREAM). These supplies may be used any way you want during the designing, building, and testing phases (through November 9). A new set of identical building materials will be provided to each team on competition day (November 10).

**Construction.**
November 10, 2007 is the day of the competition and one hour maximum is granted for construction of the device. At the start of construction, the materials will be issued to each team for their use. At the end of construction, each team must return any unused materials in their original state.

Any materials not directly used during construction, but required for the preparation of the demonstration must not be returned, but left at the construction site. Each team will have to transport their device from the construction site to the demonstration site.

**Start of the Demonstration.**
After construction, each team will have to demonstrate their device. The sequence in which each team demonstrates their device will be determined by the intermediate ranking achieved during construction. This intermediate ranking is based on the amount of materials and time used for the construction of the device. (See Scoring Methodology document.) The team with the lowest ranking will be the first team to demonstrate their device.

**Preparation time.**
After transport of their device from the construction site to the demonstration site, each individual team will be granted two minutes (maximum) preparation time from the start of the
demonstration to the actual release of the ball in the virtual space. In this preparation time, the team can set up their device and prepare for the release. The preparation time starts as soon as the device is brought into the virtual space. When “ready” for the actual demonstration, the team indicates this to the judges.

Release.
Release is defined as the release of the object or the release of the device holding the object within the virtual space. The judges indicate the “Start” moment by counting down: “3, 2, 1, Go”. On “Go”, the object (or device) must be released and the clock starts measuring the time. Immediately after release, no persons and/or body parts are allowed inside the virtual space. Only object and device may then be within the limits of the virtual space.

Object Travel Time.
The travel time of the object is measured from the moment of release until the first contact of the object with the table top surface. Maximum travel time is 240 seconds. Optimum travel time is 120 seconds.

End of demonstration / end of contest.
The demonstration ends either at the moment the object makes first contact with the table top or after 240 seconds have expired (whichever comes first). After this, the team must remove their device from the demonstration area.

MATERIALS:
The materials listed below will be supplied by the DREAM Engineering Competition on the day of the competition, at the start of construction. This is to ensure exactly the same materials for each team. The materials can be used to build the device and may also be used during the preparation time. The device may be temporarily fixed to the table top surface during the demonstration. Upon release, no additional materials may be applied to or taken away from the device.

<table>
<thead>
<tr>
<th>Materials Provided</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet 8.5 x 11 inch printing paper</td>
<td>20</td>
</tr>
<tr>
<td>Roll scotch tape (with dispenser)</td>
<td>1</td>
</tr>
<tr>
<td>Rubber band thin</td>
<td>3</td>
</tr>
<tr>
<td>Rubber band thick</td>
<td>2</td>
</tr>
<tr>
<td>String (200 cm long)</td>
<td>1</td>
</tr>
<tr>
<td>Pencil HB</td>
<td>4</td>
</tr>
<tr>
<td>Ballpoint pen</td>
<td>2</td>
</tr>
<tr>
<td>Paperclip small</td>
<td>4</td>
</tr>
<tr>
<td>Paperclip big</td>
<td>4</td>
</tr>
<tr>
<td>Magnet</td>
<td>4</td>
</tr>
<tr>
<td>Binder clip small</td>
<td>2</td>
</tr>
<tr>
<td>Binder clip large</td>
<td>2</td>
</tr>
<tr>
<td>Balloon</td>
<td>2</td>
</tr>
<tr>
<td>Plastic Ruler</td>
<td>1</td>
</tr>
<tr>
<td>Tacks</td>
<td>6</td>
</tr>
<tr>
<td>Eraser</td>
<td>2</td>
</tr>
</tbody>
</table>

TOTAL # of ITEMS: 60

OBJECT:
The object is a table tennis ball that will be provided by the DREAM Engineering Competition. Two balls will be provided to each team during the design/build/test phase and another new ball will be provided at the start of the build phase during the actual competition. The weight of this ball is 2 grams and the size 40 mm (1½ in). The object cannot be modified or deformed in any way. If necessary for the demonstration, the object may be fixed to other materials with tape.
TOOLS:
The tools listed below are the only tools that may be used during the construction phase and preparation phase. The tools shall not be present inside the virtual space during the actual demonstration.

- One pair of scissors
- Tape dispenser
- Perforator (hole puncher)
- Pencil sharpener

These tools will not be provided during the design/build/test phase, but will be provided by DREAM on the day of the engineering competition.

RESTRICTIONS, LIMITATIONS AND FURTHER EXPLANATORY NOTES:
- The demonstration can only be executed once.
- First contact of the object with the table top surface is the end of the demonstration.
- Only the footprint of the virtual space is indicated by tape. The tape is part of the footprint.
- The object and device must stay within the boundaries of the virtual space until first contact of the object with the table top surface.
  It is recognized that this requirement is difficult to check. A small violation of this rule is accepted and the judges will be responsible for determining a valid or disqualified demonstration.
- The demonstration always ends 240 seconds after release.
- Not provided as a material or as a tool, and as a safety precaution, flames and fire are not acceptable prior, during or after the demonstration.
- A device that fails during the demonstration can not be restarted and no points will be awarded for travel time.
- The table top surface is horizontal.
- Ambient conditions of the demonstration area may not change during the demonstrations. For example:
  - Wind speed to be constant (below 0.05 m/s),
  - Air pressure to be constant (variation during demonstration max. 0.5 %)
  - No shaking or vibrations (incl. sound)
  - No variations in the direct environment outside the virtual space that can influence the objects within the cube (magnetic forces, quantities of metal)
  - No variations in other forces (gravity, photons) in the direct environment that can influence the objects within the virtual space.
- Seconds will be used as the smallest increment of time measurement.
- Virtual space and table top surface may not be moved during a demonstration.
- Distance between non-participants and the demonstration table shall be at least 2 meters.

SCORING:
The winning team is the team with the highest number of points. Scoring is comprised of three components:

1. Construction time. This is a linear function.
   The less time that is used, the more points earned.
2. Return of unused materials after construction. This is a linear function.
   The more materials that are returned (i.e. not used), the more points earned.
3. Travel time during demonstration. This is a hyperbolic function.
   The closer the travel time approaches 120 seconds, the more points earned.

The total number of points for each team is the sum of these three components, construction time, returned construction materials, and travel time. The scoring is described in more details in the Scoring Methodology Document.
QUESTIONS AND ANSWERS:

- Contact Laura Campo at lcampo@rice.edu or (812) 573-9164

- Answers to any questions will be made public at the following URL: http://www.owlnet.rice.edu/~lcampo/DREAM_Competition_Questions.doc
This document further describes the scoring methodology for the 2007 DREAM Engineering Competition, Just in Time.

As stated in the Competition Rules and Material List document, there are three components for scoring:

1. Construction time.
2. Return of un-used construction materials.
3. Travel Time during demonstration.

Each of these components is described below.

1. **Construction Time:**

   This is a linear function. The less time that is used, the more points earned.

   The maximum Construction Time is one hour, which results in zero points. The theoretical minimum Construction Time is zero seconds, which results in 300 points.

   Time is measured in whole seconds and recorded in “h:mm:ss” format for hours (h), minutes (mm) and seconds (ss).

   ![Construction Time Score](image)

   The formula below provides the corresponding score, $S1$ for construction time. $CT$ is defined as the Construction Time in whole seconds between 0 and 3600.

   $$ S1 = 300 \times \frac{3600 - CT}{3600} $$
2. **Return of Un-used Construction Materials:**

   This is also a linear function. The more materials that are *not used* and are *returned*, corresponds to more points earned.

   The total amount of materials available for use is sixty (60). The minimum amount of returned material items is zero (i.e. everything is used), which results in zero points. The theoretical maximum amount of returned material items is 60 (nothing used), which results in 200 points.

   All materials are measured one by one. For example, one sheet of paper counts as one, for a total of 20 and the roll of tape counts for one, as soon as it is being used. There is no weighting factor for items.

   ![Materials Returned Score Graph](image)

   The formula below provides the corresponding score, $S_2$ for unused and returned materials. $MR$ is defined as the amount of Material items Returned.

   $$S_2 = 200 \times \frac{MR}{60}$$
3. **Travel Time during Demonstration:**

This is a hyperbolic function. The closer the travel time approaches 120 seconds, the more points earned.

For a travel time of 0 seconds, the score is 1 point. For a travel time of 240 seconds, the score is also 1 point. Travel times greater than 240 seconds result in no score for travel time. For an exact travel time of 120 seconds, “JUST IN TIME”, 15,000 points are earned.

Time is measured in whole seconds and recorded in “second” format, e.g. 125.

The formula below provides the corresponding score, \( S_3 \) for travel time. \( TT \) is defined as the Travel Time in whole seconds between 0 and 240.

\[
S_3 = \frac{10,000}{\sqrt{|TT - 120|}} - 912
\]

In the case where \( TT = 120 \), \( S_3 = 15,000 \).
The Total Score, TS for the 2007 Friendly Competition is a summation of the three scores explained above.

\[ TS = S1 + S2 + S3 \]

**Explanation of the reasoning behind the scoring method:**

From the detailed descriptions above, it should be clear that in the “time window” close to a travel time of 120 seconds, the score \( S3 \) has the highest impact on the Total Score. In this window, the summation of \( S1 + S2 \) only serves to distinguish teams with identical travel times, which nevertheless are likely to occur. Therefore, don’t ignore the construction time and amount of materials used, even if you target for the Bull’s Eye of exactly 120 seconds. You might not be the only team with exactly 120 seconds...

In the time windows closer to a travel time of 0 seconds and 240 seconds the score \( S3 \) has only a limited impact on the Total Score, so in these cases a fast and smart construction can significantly impact the overall ranking. In case something goes wrong during the demonstration, or at least different from planned, the construction time and construction materials might make the difference with the competing teams.

In other words, building faster and smarter will make “a” (and perhaps even “the”) difference, no matter what the travel time is.