AC 2005-1483: CREATIVE ENGINEERING: HELPING NINTH GRADE STUDENTS DISCOVER ENGINEERING

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Abstract

Many students who graduate high school are not prepared with the educational tools to successfully pursue an engineering degree. Graduation from engineering colleges has declined significantly from its peak in 1988, reflecting a national malaise in interest in the engineering profession by today's youth. By fostering in high school students the skills and knowledge to more fully understand the opportunities a career in engineering affords them, we hope to increase the number of interested and prepared students who enter engineering colleges.

Working with ninth-grade students at the new Denver School of Science and Technology provided an opportunity to teach a hands-on, high school engineering elective course, targeted at inspiring students to explore engineering as a future career path. Through the support of an NSF GK-12 grant, the Integrated Teaching and Learning Program developed an engineering elective that submerses ninth-grade students — most from populations traditionally underrepresented in the field of engineering — in the creative engineering design process, including emphasis on cooperative teamwork, engineering design/build projects and making technical presentations.

The goals of the *Creative Engineering* elective are to enhance student learning through experiencing relevant, hands-on, inquiry-based engineering; to instill knowledge of engineering as a career through an understanding of the pervasiveness of engineering in our world; and to provide an appreciation of engineering as the creation of things for the benefit of society. In this paper, we examine the planning, implementation and assessment results associated with developing a 12-week, hands-on, engineering design-focused ninth-grade elective course. Additionally, we discuss how a partnership between a newly developed urban public high school, engineering graduate students and faculty, and enthusiastic high school students and parents can make a significant impact on the knowledge of and interest in engineering among high school students.

Why Engineering in High School?

Science and math are fundamental K-12 subjects taught throughout the world. According to 2003 TIMSS results,[1] although average eighth-grade achievement in science for U.S. girls and boys increased since the 1995 and 1999 assessments, a measurable difference continues between countries. On average, the eighth-grade students in seven other countries continue to outperform U.S. eighth-grade students. The areas of U.S. improvement were primarily in the subjects of physics and earth science, with little noticeable improvement in chemistry, environmental and life sciences. The TIMSS data also show that U.S. students increased their performance in math from 1995; however, in 2003, U.S. eighth-grade students were still outperformed in math by their peers in seven countries. The primary areas of improvement among U.S. students were in algebra and data collection; there were no measurable improvements in geometry and measurement achievement. Also, within U.S. populations, students in public schools with higher poverty levels (as determined by the number of students qualifying for free and reduced lunch) continued to demonstrate lower science and math achievement scores compared to their peers in public schools with lower poverty levels. Even though there have been improvements in math and science achievement by U.S. eighth-grade students since 1995 and 1999 TIMSS assessments, educational gaps persist. These include a deficiency in whole-subject learning, an inability to rank among top testing scores (compared to their peers in other countries who continually excel), and a continued disparity of student achievement in schools with greater numbers of high poverty students.

Engineering is a real-world application of the fundamental science and math principles that students learn early in their education. Schoolroom experiences in an engineering context can provide a gateway to creative, real-life problem solving and exploration in all areas of science and mathematics. By experiencing the engineering design process first hand, students begin to see how engineering ingenuity and inventions touch and shape their everyday lives.

Teaching engineering to high school students has many benefits. Providing early exposure to engineering and technology has the potential to open up new lifelong pursuits. It affords students the opportunity to make informed career choices rather than relying on high school guidance counselors or teachers to suggest engineering as an educational path because a student demonstrates strong interest or capability in math and science. A high school engineering course cements students' science and math knowledge while allowing them to seek creative solutions to complex problems and appreciate the overarching engineering concept of *creating things for the benefit of society*. It also encourages them to select more rigorous courses as they prepare for college. We contend that high school students who complete courses in engineering have a better understanding of, and a more solid foundation for, the mental processes and perspectives needed to achieve success in an increasingly technologically-driven world.

The *Creative Engineering* Course

With the benefits of teaching engineering at the high school level in mind, the Integrated Teaching and Learning (ITL) Program at the University of Colorado at Boulder's College of Engineering and Applied Science partnered with the Denver School of Science and Technology (DSST) to develop and teach an engineering elective course for ninth-grade students. Designed

to be 12-weeks in duration and team-taught by two university engineering instructors, the course fits into the high school's trimester system. *Creative Engineering* was one of several choices students could select for one of their elective periods. The course was fully enrolled in fall 2004, its inaugural trimester, with 31 students.

Course Goals — The intention of the DSST *Creative Engineering* course is to enhance student learning through the teaching of interesting, hands-on, design-based engineering. In planning the pilot, the instructors wanted to positively impact students by instilling in them an understanding of engineering as a career and the pervasiveness of engineering in their world. Furthermore, the teaching team hoped to promote an appreciation of engineering as a means for *creating things for the benefit of society.* Lastly, it was the aspiration of both instructors to cultivate a contagious enthusiasm for engineering to a diverse population of students, many of whom are from backgrounds typically underrepresented in the field of engineering.

Student Population — As discussed earlier, a deviation exists between student achievement in schools from higher-poverty areas and their counterparts in schools with lower-poverty levels.[1] The setting for the described engineering course is a newly established, urban public charter school — the Denver School of Science and Technology (DSST), in Denver, Colorado. By charter, DSST must enroll at least 40% students who qualify for free or reduced lunch and at least 45% female students. The inaugural ninth-grade student cohort, the class of 2008, was comprised of 46% low-income students, 46% female students, 22% Latino students and 44% African American students — greatly representative of students from populations typically underrepresented in engineering. The *Creative Engineering* course was enrolled to capacity; this pilot class reflected the school population ratios in terms of low-income students, females and students of color.

A *Creative Engineering* student plans her design project.

Course Setting — Because the new school building was still under construction, the setting for the first four months of the inaugural school year for DSST and the *Creative Engineering* course was the ground and second-level floors of a nearby vacant school building; although old, it sufficed for the short period. Furniture and space was at a premium in this setting. Although reliable laptops and projectors were available, chairs and tables were rented and several classrooms were shared with other elective courses three times weekly. Student teams made do around crowded tables that did not allow them much room to spread out for project design and development.

Instructors — The development and instruction of a new high school engineering elective is time consuming and intellectually demanding. The ideal instructor would bring a strong academic background, a commitment to the program (i.e., to promote engineering to youth), and experience working with youngsters. Involving persons who already have teaching and engineering experience is an advantage, both to the program development and the depth of the students' oftentimes first encounter with engineering.

Course development and instruction was accomplished by two members of the ITL outreach team: a university faculty member with a background in civil engineering and secondary education, and a mechanical engineering PhD student who is also an NSF GK-12 Fellow. Both instructors teach courses at the university level, are experienced teaching high school students, have practical knowledge of the engineering design process and share a passion for bringing engineering in to the K-12 arena.

Like other DSST elective courses, the pilot course met three times weekly, each for 50 minutes, for one 12-week trimester. A flexible team-teaching model was followed: each Tuesday class was conducted by one instructor, the Friday class was instructed by the other, and both were present for the Wednesday course meeting. This scheduling allowed each instructor to contribute to the class as well as fulfill her university commitments.

Connection to Educational Content Standards — The hands-on activities presented in the *Creative Engineering* course are mapped to Colorado state educational science standards. The class content also aligns with the National Research Council's National Science Education Standard[2] *Science and Technology Content Standard E*: Regarding abilities of technological design and understandings about science and technology. Additionally, the class meets the following performance indicators set forth by the International Society for Technology in Education (ISTE) National Educational Technology Standards (NETS) student framework.[3]

- Standard 1: Basic Operations and Concepts
- Standard 3: Technology Productivity Tools
- Standard 6: Technology Problem-Solving and Decision-Making Tools

Course Components — The *Creative Engineering* course introduces general engineering concepts and practices to students working in teams of three or four students. Throughout the 12 weeks, students were introduced to engineering disciplines, experienced teambuilding and brainstorming practices, explored the design process, learned about aesthetics in engineering, made technical presentations, learned the basics of isometric sketching, used new software applications and became familiar with project management concepts.

The course began with an introduction to engineering disciplines and brainstorming, encouraging students to explore various disciplines and practice brainstorming through team-fashioned storyboards. Design process fundamentals, and teambuilding and brainstorming skills were developed through teamwork exercises and a weeklong kickoff design/build activity. During the activity, students worked through a design loop, designed the base of a model trebuchet (a medieval launching device), and built a trebuchet model capable of launching a grape 20+ feet.

For the next four weeks, students explored the value of aesthetics to engineering design, learning how form follows function by in-depth examination of everyday items. Using PowerPoint®, student teams learned how to create technical presentations. Students also practiced isometric sketching, followed by an introduction to solid modeling logic and the SolidWorks® CAD design software.

During the last four weeks, teams focused on creating a kinetic sculpture design project for presentation at a school-wide, end-of-term design expo. This final project encompassed all subject matter that was taught during the trimester. Student groups brainstormed and selected a kinetic sculpture that followed an "innovation" theme and could be constructed as a small, desktop-size model. Project requirements included a design loop log, isometric sketch, SolidWorks® CAD parts drawings and a technical presentation.

Design Expo — The students' experience culminated with an engineering design expo to showcase their kinetic sculpture design/build projects. Enthusiastic student teams practiced their technical presentations before presenting to the entire class, and set up tables in the lunch room for their peers, teachers and parents to visit and learn about what they had worked on for 12 weeks. Each team demonstrated a prototype of their sculpture project, augmented by two laptops, one with their technical presentation and one with their computer-generated (via SolidWorks®) 3-D model sculpture design. Expo guests were briefed on the class goals and projects, and invited to visit the team displays to ask the students questions about the design process and prototype fabrication. Expo attendees voted for their favorite design — the People's Choice. The student team that won the vote was acknowledged to the entire school during morning announcements and given the opportunity to create their sculpture using more robust materials in the school's new, state-of-the-art fabrication center.

High-school student "engineers" explain the motion of their kinetic sculpture at an end-of-term design expo.

Assessment and Evaluation

For the pilot *Creative Engineering* course, 26 of 31 students (14 boys, 11 girls, 1 gender unknown) completed pre- and post-course self-assessment surveys on self-confidence in design, engineering methods, communication and teamwork skills. Students were also assessed on course content knowledge by completing multiple-choice, pre/post tests on the topics of design, communication skills and teamwork. Finally, students answered a series of open-ended questions addressing their experience in the class.

Student skills survey results are presented in Table 1. A paired value t-test was used to test for significant differences between the pre- and post-test assessments. Results indicate that students reported a significant gain in confidence for three skill sets: design, engineering methods and communication skills. The strongest results were for design skills, with students reporting a 21% gain in confidence across the 12-week course. Students' confidence in their teamwork skills was high at the beginning of the semester and did not change significantly during the course. No differences were found between genders.

Table 1: Changes in students' skills confidence during the *Creative Engineering* course.

Skills	Pre-Course Confidence		Post-Course Confidence		Change
	Mean	Standard Deviation	Mean	Standard Deviation	
Design	3.01	1.05	3.65	.76	+ 21%*
Engineering Methods	3.47	.82	3.96	.77	+ 14%*
Communication	3.72	.90	4.06	.73	+ 9%*
Teamwork	4.30	.52	4.25	.70	- 1%
Ranked on a 1-5 scale, with 1 being lowest and 5 being highest.			*Significant p < .05		

A repeated measures ANOVA statistical procedure was used to test for significant differences between the pre- and post-content tests. Test results indicated a significant gain in content knowledge by the students; their pre- to post-test scores increased from 37% to 57% — a 54% gain. Significant gender differences were also found: content scores for girls increased from 30% to 47% — a 57% gain, while content scores for boys increased from 43% to 64% — a 49% gain.

To provide feedback on the course itself, students answered a number of open-ended questions on relevant topics, such as their inspiration to select the elective course, what they liked best about it, what they would change about it, and how it changed their perspective on engineering. Students most frequently reported that their inspiration to select the course came from their love of building and designing things, working on the computer or their positive experience with a weeklong ITL pre-engineering workshop taken the summer before the course (13 students enrolled in the *Creative Engineering* elective took the summer 2004 engineering workshop).

Students most frequently reported that they liked the hands-on building portion of the course, including the trebuchet project, the SolidWorks® CAD program and the four-week design/build project. One student commented, "Building was cool." Another student wrote that he liked how social and interactive the building projects were. Student suggestions for improvement included shorter lectures and having more time in class.

Asked if the course changed their perspective on engineering, 39% of the students answered "yes" (many students indicated that they had a high respect for engineering at the start of the course, due to their previous exposure during the engineering summer workshop). They most frequently reported that they did not realize how fun and interesting engineering could be. One student commented, "Engineering seems a lot more interesting now," while another student said, "It made me more interested in becoming an engineer."

Sustainability: What is the Future of *Creative Engineering?*

The partnership developed between CU-Boulder's engineering college and the Denver School of Science and Technology has long-lasting potential. The college and DSST are committed to

expansion of the *Creative Engineering* elective topics and an agreement that guarantees admission to the engineering college for DSST graduates who meet specific criteria (i.e., grade point average, completion of *Creative Engineering* electives, math SAT achievement and participation in summer CU high school engineering programs). Ongoing financial support for supplies and instructor compensation will be sustained initially through grants and raised funds.

As this design/build course evolves, we expect to offer a wider range of engineering design topics, with the intent to attract different groups of students each trimester. We foresee the course emphasis shifting from general engineering design/build topics to specialized topics that appeal to fewer and different students, for example, biotechnology or the role of materials in the fashion industry. Regardless, the common theme of every *Creative Engineering* course will continue to be an introduction to engineering design-based, team-oriented projects that inspire students to *create what they dream*.

High school students work together to complete their team's final engineering prototype.

With regard to future course instruction, several DSST teachers have expressed an interest in co-teaching this course with university professors or engineering graduate students from CU-Boulder. Two DSST teachers with backgrounds in engineering have also expressed a desire to teach future electives in the area of their expertise — biomedical and computer systems engineering. Securing teachers who are committed to investing their time and energy in *Creative Engineering* is invaluable to the sustainability of an alternative high school course elective.

We also intend to guide students to create folios and products or prototypes to demonstrate what they have learned and created during one or more trimesters of the course. We have plans to continuously build relationships with these youngsters through high school, to see them on their way to college and beyond.

Lessons Learned

The *Creative Engineering* elective for ninth-grade students was a tremendous success. We learned that the development and instruction of this course was more time intensive than predicted, but also more rewarding. We also learned that the students responded to clear and defined expectations set at the beginning of the course, followed by strict adherence to those guidelines. With clear expectations in place, the class ran more smoothly and students gained more from the experience.

We learned that our expectations for the amount of course material that could be covered during the trimester were too high; we made mid-trimester course adjustments to reflect the learning pace of our students. We also learned that the support of the high school staff, faculty and parents was invaluable to the success of the course. The full-time teaching staff eagerly shared

their classroom ─ and, more importantly, their insider school expertise (helping the instructors understand myriad school rules, planning issues, etc.). A sense of accomplishment was achieved at the design expo, watching the students show off their hard work to peers, parents, teachers and administrators.

We learned that the 50-minute time slot was too short for a deep dive into the engineering process. After classroom set up and clean up time, the students were left with inadequate time for the investigation and solidification of ideas. In response to this, the instructors have requested that the elective course be offered at the end of the school day, allowing for interested students to use after-class time for project completion. Until that schedule change can be put in place, the course was modified for easier clean up and more streamlined instruction at the beginning of class, supplemented with individual instruction, as needed.

Conclusion

Creating a partnership between a high school, engineering faculty and graduate students, and enthusiastic students, staff and parents can make a difference in the knowledge of and interest in engineering among high school students. The process for the successful implementation of an engineering elective for high school students includes defining goals; developing challenging and engaging, hands-on, standards-based engineering projects for students; involving enthusiastic instructors; and partnering with school staff and parents. The urban school setting is an ideal venue for engaging students — especially those with backgrounds typically underrepresented in engineering — in the creative aspects and methodology of engineering. This course model is a practical approach to help students gain experience in teamwork, communication, project management and technical skills that will help them in their post high school career paths.

As demonstrated in this *Creative Engineering* course, students are motivated by the hands-on building aspect of a design/build projects course. Through the experiences of learning the fundamentals of the engineering design process, today's youngsters can become aware of a broader range of career options, including the in-demand fields of engineering and technology. The 2003 TIMSS data[1] documents the achievement gap in math and science between students in the U.S. and other developed countries. Opening the doors early to alternate educational avenues for high school students is essential to improve the general technological literacy of our graduates, and widen their understanding and appreciation for potential career options — all of which advances the technological progress and economic competitiveness of our nation. The *Creative Engineering* high school course elective model is one means of accomplishing these goals.

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