

Engineering for High School Students

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Abstract –*Introduction to Engineering* is a course that was developed by the Westlake High School Math/Science Magnet Program with the goal of exposing students to engineering concepts and disciplines. The school's magnet program prepares students for future study and careers in math, science, engineering and technology. The *Introduction to Engineering* course provides a foundation in engineering theory that utilizes higher-level mathematics for problem analysis and conceptual design. It is a project-based course that involves computer-aided design and technology. This paper will present the structure of the course, best practices for projects, and tracking of the students to determine how many of the students end up majoring in engineering.

Keywords: Engineering curriculum, high school

INTRODUCTION

The challenge of recruiting students into science and engineering careers begins in the K-12 education system [3]. Several reports have been published that address the shortfall in the number of US students pursuing careers in science and engineering. The National Academy of Engineering's Educating the Engineer of 2020: Adapting Engineering Education to the New Century [4] and The Business-Higher Education Forum's A Commitment to America's Future: Responding to the Crisis in Mathematics and Science Education [1] have been published suggesting plans to encourage students to enter science and engineering programs. According to the *Educating the Engineer of 2020* document, starting engineering education during the K-12 years would have a significant impact on the engineering profession [4]. This early exposure would increase both the quality and quantity of students pursuing engineering degrees and careers.

This paper describes the *Introduction to Engineering* class at Westlake High School, a 98% African American school in Fulton County, Georgia. The course is part of the magnet school's math and science program, and is designed to: 1) introduce engineering concepts and practices; 2) analyze problem solving from an engineering perspective; and 3) utilize higher mathematics in real world problems. This paper will present the structure of the course, best practices for projects, and tracking of the students from the 2003-2007 academic years.

STUDENT AND TEACHER ENHANCEMENT PARTNERSHIP

In 1999, the National Science Foundation (NSF) initiated a new type of graduate student support through the NSF Graduate Teaching Fellows in K-12 Education (GK-12) program. Students receiving GK-12 fellowships are required to interact directly with K-12 teachers in an attempt to improve K-12 education and the pedagogical and communication skills of the Fellows. In return, graduate Fellows receive an annual stipend and a tuition waiver. In the spring of 2001, Georgia Institute of Technology received a GK-12 grant to support its Student and Teacher Enhancement Partnership (STEP) program [2] and to place twelve graduate students per year in Atlanta area high schools.

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The broad goals of the GK-12 initiative and the STEP program are:

1. To broaden the education of science, technology, engineering, and mathematics (STEM) graduate students to include intensive experiences in educational pedagogy and process;
2. To encourage the participation of STEM faculty and students in the difficult issues facing K-12 educators through the nurturing of university-school partnerships;
3. To assist K-12 teachers in their endeavors to improve classroom instruction; and
4. To help schools improve K-12 student achievement in STEM.

To address these goals, STEP forms partnerships at each of six metro-Atlanta high schools that consist of two Georgia Tech graduate STEP Fellows, a teacher STEP coordinator, and additional teachers and administrators from the school. Each STEP team then designs an action plan for the year based on the needs of the school, and the talents and interests of the particular STEP Fellows. During the 2007-2008 school year, one STEP Fellow directly assisted the Westlake High School *Introduction to Engineering* teacher with the instruction of the course and development of hands-on activities and projects to demonstrate introductory principles in five engineering disciplines.

WESTLAKE HIGH SCHOOL

Westlake High School is located in a middle socio-economic and primarily African American area of southwest Atlanta, Georgia on Fulton County. The high school was formed in the fall of 1988 by the consolidation of Westwood High School and Lakeshore High School, and in 2007 enrolled 2,065 students, 98% who were African American, and 40% who were eligible for free/reduced meals. After the 2007-2008 school year, 88% of the students went on to some kind of post-secondary education. The Georgia Department of Education and also the Southeastern Association of Colleges and Schools accredited Westlake High School as the magnet school for math and science for South Fulton County in 1999.

Westlake High School's Math/Science Magnet Program prepares students for the academic and career fields of math, science, engineering, and technology through rigorous instruction, relevant experiences and supportive relationships. Students must complete twelve credit hours of math and science courses approved by the magnet program coordinator in order to receive a magnet seal on their diploma. The freshmen and sophomore year requires honors courses in biology, geometry, algebra II, and chemistry, and during these two years students also take a research methods course that requires them to develop a research paper that is submitted to the school science fair. During the sophomore year, students take a math technology course that incorporates statistical analysis, enabling the students to perform hypothesis testing as part of their science fair topic. During their junior and senior year students choose a course of study focused around medical science, engineering, or digital media/computer science. Students in the medical science program of study take courses that include human anatomy, genetics, microbiology, honors pre-calculus, AP chemistry and AP biology. Students in the engineering program of study take pre-engineering concepts, introduction to drafting, introduction to engineering, honors pre-calculus, AP calculus AB, and AP Physics B. Students in the computer science program of study take web design, digital media concepts, beginning programming, honors pre-calculus, and AP computer science. Georgia Institute of Technology STEP Fellows have assisted and sometimes instructed in many of these courses ranging from honors geometry to AP Physics.

Typically during their sophomore to senior year, students engage in extracurricular clubs including but not limited to Medical Sciences Club, Math Team, National Society of Black Engineers (NSBE) Jr., Engineers Without Borders (EWB), Robotics Team, or Digital Design Club. Georgia Institute of Technology STEP Fellows often assist with these clubs by providing instruction, conducting activities, and coordinating field trips. Magnet students compete as part of these clubs and have won the NSBE regional and national Try-Math-A-lon competitions and received the EWB Pre-College Chapter Award. Also, some students participate in summer research internships at Georgia Institute of Technology for five weeks through the Center for Education Integrating Science Mathematics and Computing (CEISMIC).

One hundred percent of students who graduate from the Magnet Program attend a variety of colleges and universities including Georgia Institute of Technology, Harvard, Morehouse, Spelman, Princeton, Clemson, Georgetown, Xavier, North Carolina A & T, Yale and University of Georgia. On average, 99% of the magnet students have been eligible for the Georgia's HOPE scholarship, awarded to students who maintain a B average in high school, and 65% of the magnet students have received scholarships other than HOPE for the years 2003-2007.

COURSE DESIGN

The *Introduction to Engineering* course is a year-long elective for magnet students taught by a teacher who was trained as an engineer. It consisted of hands-on design activities and was structured to teach the origins of science and engineering, engineering ethics, the design process, the application of higher-level mathematics and science to engineering problems, and basic research and problem solving techniques. The course also provided a presentation covering introductory concepts in five engineering disciplines. The syllabus topics included:

- First Principles of Systematic Thought
- What is Engineering?
- The Origins of Science and Engineering
- Mathematics and Science Review
- The Engineering Ethics and 7 Useful Charts
- Overview of Engineering Design
- Overview of Engineering Disciplines and Discipline Projects

The first semester of the course was focused on lecturing and providing a foundation for engineering. The second semester of the class was focused on hands-on projects to demonstrate the engineering concepts. The projects ranged from Rube Goldberg designs to circuits labs and were designed to stimulate student interest in design and reinforce theory and concepts learned in the course. The projects also gave the students an opportunity to experience what engineers do on a smaller scale.

As an initial project to understand what engineering is, students were asked to disassemble a doorknob and/or computer mouse and document how it works. After understanding how the computer mouse currently works, the students were challenged to come up with an innovation to modernize the doorknob and/or computer mouse. From this project students were able to differentiate the difference between science and engineering—namely that science is understanding what exists, and engineering is the application of math and science to create or improve utility. After having an understanding of the role of an engineer, the students were divided into groups to research and present the origins of science and engineering. The groups presented on engineering in the Kemet (Ancient Egypt), Mesopotamian, Indus Kush (Ancient India), Greek, Roman and Chinese cultures. This module served to enlighten the students that modern day engineering originated with the Great Wall, Egyptian Pyramids and the Great Bain drainage system.

To ensure a solid mathematics and science foundation, time was spent reviewing core concepts before beginning instruction in the individual engineering disciplines. Algebra II, basic physics, chemistry and statistics principle were reviewed. Next, students were involved in role playing to understand the importance of engineering ethics when designing new technology and working as a professional. A module called “Seven Useful Charts” introduced the fishbone diagram, histogram, run chart, flowchart, scatter/correlation plot, Pareto chart, and control chart as tools for effectively analyzing data, reducing variation and improving results.

To incorporate a social engineering concept into the course, the STEP Fellow had the students design an emergency shelter. The students were given the scenario that individuals have been stranded in an area from which they cannot be rescued via airlift or ground transportation for three days. The team of student engineers were instructed to design a viable temporary shelter that would be released by air to the stranded individuals to protect them for a few days until a rescue team arrived. The two-person teams went through the engineering design process of drafting proposal designs and designing prototypes of their shelters. The shelters had to be low cost structures that could withstand 20 degree wind-chills, gusts of wind up to 25 miles per hour, and rain. The prototypes were tested in class using a fan to simulate wind gust and pouring water on the shelter to ensure it could withstand rain. The teams presented their prototypes and the team with the most viable prototype won the mock bid for the business. The project illustrated the importance of social action through engineering as well as the use of project management and facilitating a set of temporary tasks to achieve the goals and/or requirements of stakeholders.

As motivation for the students to assume more control of their learning experience, students designed some of their own projects during the second semester of the course. For each of the disciplines, students had the opportunity to determine the guidelines for their project based upon their personal interests. The instructor who developed the course incorporated the use of a learning contract during the second semester which included core and optional

projects. Students had to complete a core set of projects that included an alternative fuel vehicle theoretical design, solar cooker, and comparison of alternative cooling designs. The social concept was also included in the solar cooker project which some of the students implemented in Arusha, Tanzania as part of their EWB chapter's work project. In addition, students proposed and negotiated with the instructor on additional optional projects and on the associated standard of evaluation for each project, with the instructor having final approval. Examples of optional projects include bridge design and modeling, series and parallel circuit model house design, and hovercraft design and modeling. At the end of the semester the students had to defend a portfolio of their work from both the core and optional projects in a one-on-one interview with the instructor.

STUDENT TRACKING

The data reported in Table 1 summarizes four of the years the course was taught, 2003-2007. During this time three different instructors taught the class. Mr. Douglas Edwards, one of the authors on this paper, designed the course and prior to joining the Westlake staff, had been a practicing electronics engineer with the US Air Force for eight years. He taught the course from 1998 to 2000, and again from 2003-2004 and instituted the school's NSBE Jr. Chapter. He was promoted to magnet school coordinator in the spring of 2004, and thereafter oversaw the program, but for several years did not teach the actual course. The second instructor, who taught the course from 2004-2005, had worked in industry as an electrical engineer for twelve years and instituted a robotics team that competed in the FIRST robotics competition during the 2004-2005 school year. The third instructor was a mathematics teacher who began his college studies in civil engineering then switched to mathematics. Both of these two instructors resigned from the school after one year, illustrating the difficulties of maintaining a qualified engineering teaching staff in challenging school situations. This teacher turnover left the engineering program with low enrollment and reduced student interest. For the 2006-2007 school year, Mr. Edwards again took over the class, increasing the enrollment from seven in the 2005-2006 school year, to nineteen in 2006-2007. During that year one of the STEP Fellows, in collaboration with Mr. Edwards, instituted the first ever EWB high school chapter.

Overall, 47.1% of the students who took the class between 2003 and 2007 entered college as declared engineering majors. All of these students were also involved in an extra-curricular engineering club (NSBE Jr., EWB or Robotics Club) at some point during their high school matriculation. This is interesting to point out because students have mentioned to the STEP Fellows and course instructors that their participation in the engineering clubs complemented the engineering theory they learned in the course. During the 2004-2005 academic year the entire class served as a team for the Robotics Club, then for the 2006-2007 academic year, the entire class was involved in EWB. In both cases, these engineering-based club projects provided the students with an extracurricular application and outside audience for the academic work presented within the class. For the robotics class project, the outside audience was the FIRST competition judges and spectators. For the EWB team, the outside audience was the EWB conference participants, where students presented their solar cooker design in March of 2007, and the Imbaseni villagers in Arusha, Tanzania where the students implemented the design in July of 2007. The 2004-2005 and 2006-2007 classes had the highest percentage of students entering engineering, at 55 and 57.9% percent, respectively.

Table 1. Introduction to Engineering Course Demographics and College Majors

Academic Year	2003-2004	2004-2005	2005-2006	2006-2007
Students in the class	22	20	7	19
Female (%)	50	30	57	42
Male (%)	50	70	43	58
Participated in NSBE, EWB or Robotics during class (%)	77	100	57	100
Majored in engineering (%)	36.4	55	28.6	57.9

There are several factors that may have contributed to the varying results across the years; the instructor of the course, the degree of involvement of STEP Fellows, and the participation in extracurricular clubs are three obvious variables that changed. There were also differences in the number of presentation from working engineers and graduate students, which might have contributed to some of the variation in student's desire to major in engineering. Another potential reason for the varying number of students pursuing majors in engineering is the student's classification when taking the class. Of the students opting to major in engineering, 78% were juniors when taking the *Introduction to Engineering* course. This may have provided them with more time to explore engineering as a career, as opposed to the seniors who were applying to college while taking the course. The students deciding not to major in engineering may also have been more engaged in the outcome of the projects rather than the engineering design process itself. If this is the case then the class was successful in exposing the students to engineering so they could have a better idea of what engineering really means before majoring in the discipline.

CONCLUSION

The Westlake *Introduction to Engineering* course involved a variety of activities and projects that engaged, motivated, and challenged the students. Students were introduced to engineering concepts and practices; learned to analyze problem solving from an engineering perspective; and utilized higher mathematics in real world problems. The data show that coupling an introductory engineering course with an engineering-based extra-curricular club appears to be particularly effective in encouraging students to pursue degrees in engineering. Though it is difficult to determine which parts of the program were most responsible, in the end the Westlake program, even with a high level of teacher turn-over, graduated 32 primarily African American students who entered college engineering majors over a four year period. Examples like this are worth studying and emulating.

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Ashley Johnson is a PhD student in the School of Electrical and Computer Engineering at the Georgia Institute of Technology. She obtained her B.S. in electrical engineering from Florida A&M University in 2005 and her M.S. in electrical engineering from Georgia Tech in 2007. Her research focuses on biological signal processing of EEG and EMG in humans. Ashley is a recipient of the Ford Foundation Pre-Doctoral Fellowship, NSF STEP Fellowship and Georgia Tech Facilitating Academic Careers in Engineering and Science (FACES) Fellowship. As a STEP Fellow, she taught *Introduction to Engineering* and co-advised the NSBE Junior Chapter.

Douglas Edwards

Douglas Edwards is the Math/Science Magnet Coordinator for Westlake High School in Atlanta, GA. He received his B.S. in electrical engineering and MS in instructional technology. Mr. Edwards developed and first taught the *Introduction to Engineering* course in 1997. He also partnered with a former Georgia Tech STEP fellow to found the first high school chapter of Engineers Without Borders and traveled to Arusha, Tanzania with the students to work on a solar engineering project.

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