Involving High Schools Students in a University-Level Mechanical Engineering Design Competition

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Abstract

This paper documents the involvement of students from a 99% African American metro-Atlanta area high school in a sophomore-level mechatronics course at the Georgia Institute of Technology. The course contains elements of computer science, electro-mechanical sensors and actuators, and mechanical design. The wide range of skills needed to build a competitive machine in the end-of-course competition attracts interest from a wide range of students. By involving high school students in this competition, and exposing them to the university setting, we hope to attract more minority students into science or engineering, and specifically into mechanical engineering.

1. Introduction

Metro-Atlanta, like many regions of the country, is characterized by increasingly segregated schools and a large academic achievement gap between African American and Hispanic students on the one hand, and their white and Asian peers on the other. The schools in the north part of the region, considered to be some of the best in Georgia, enroll primarily non-Hispanic white and Asian students and boast SAT scores well above the state and national averages. In stark contrast, the overwhelmingly African American schools in the southern portion of the region post cumulative SAT scores over one hundred points below the already low Georgia state average. Other standard measures of academic achievement, such as Advanced Placement test scores, college matriculation rates, and need for college remediation, show the same bimodal distribution.

Clearly the reasons for these disparities are many and multifaceted. In an attempt to be part of the solution, the Georgia Institute of Technology has established partnerships with several of the local school systems, and actively explores ways to utilize the resources and talents available on the campus to implement novel interventions at the school-house level. These interventions have the potential to attract minority students into science, technology, engineering, and mathematics (STEM) fields by exposing the high school students to the university, and by convincing them that they have the ability to compete in an arena that has, up to that point, been foreign to them.

One of these experimental interventions was initiated at a 99% African American high school in DeKalb County as part of Georgia Tech's Student and Teacher Enhancement Partnership (STEP) NSF GK-12 program, and consisted of involving high school students in a sophomore-level mechatronics course.

This paper will address the details of the program, how it aligns with the high school curriculum, and the many lessons learned regarding university/K-12 partnerships. The remainder of the paper is organized as follows. Section 2 provides an overview of the Student and Teacher Enhancement Partnership (STEP) program at Georgia Tech. Section 3 presents a summary of the activities used to get the students involved. Section 4 presents a description of the mechatronics course (ME2110: Creative Decisions and Designs) at Georgia Tech and a description of the Spring 2004 Competition. Section 5 provides a listing of lessons learned. Finally, Section 6 summarizes the discussion on developing a partnership between a mechanical engineering course and a high school.

2. Student and Teacher Enhancement Partnership (STEP) Program

In 1999, the National Science Foundation 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 both 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 Tech received a GK-12 grant to support its Student and Teacher Enhancement Partnership (STEP) program and to place twelve graduate students per year in Atlanta area high schools. (See http://www.cetl.gatech.edu/services/step/overview.htm for more details.)
The broad goals of the GK-12 initiative and of 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 endeavor to improve classroom instruction; and
(4) To help schools improve K-12 student achievement in STEM.

To address these goals, STEP forms partnership teams 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 2003-2004 school year, one of these STEP teams chose to augment the opportunities offered to students at their partner school by initiating participation in a Georgia Tech sophomore-level design competition in the Mechanical Engineering Department. This paper describes the results of this initiative, and provides the lessons learned in the process. It is our hope that Georgia Tech's experience can assist other universities in forming similar partnerships with local schools.

3. Summary of Activities

The outreach activity was initiated as part of a university-high school partnership under the auspices of Georgia Tech's NSF-funded Student and Teacher Enhancement Partnership (STEP) GK-12 program. It requires an incremental approach that gradually introduces the necessary concepts within the context of the regular school schedule.

3.1 Year-One Summary

Involving the High School Teacher(s)

Our partnership began in the summer proceeding the placement of the STEP Fellow in Cedar Grove High School. The high school physics teacher, Mr. Michael Pastirik, sat in on the summer session of the Georgia Tech mechatronics course. This allowed him to gain an understanding of both the depth and breadth of the course and an appreciation of the skills required to construct a competitive machine for the end-of-course competition. The main goal of the summer, however, was to allow him to determine if and how the Georgia Tech course content could fit into the learning objectives of the physics curriculum.

Mousetrap Car Competition

During the Fall Semester, the physics teacher and the STEP Fellow adapted an older version of the Georgia Tech design competition as a six-week student project. Prior to the 2000-2001 school year, the ME 2110 competition limited the students to mousetraps and gravity as energy sources. In the high school competition, the goal was to design a car powered by mousetraps that would travel a specified distance and stop on a target. Students were grouped into teams of 2-3 students and points were awarded based on proximity to the target. The project was implemented by the STEP Fellow with input and guidance from the Physics teacher.

The competition was completed in three stages. The first stage was the development of conceptual designs. It was during this stage that the design tools used in the Georgia Tech course, such as Function Trees and Evaluation Matrices were introduced. Initially, it was difficult getting the students to brainstorm, but as they became aware of prior designs, idea generation began to increase. During this stage, it was important to help guide the students to implementable design ideas. This was also the time in the project that the connection to ideas and concepts of Physics was established. Students were encouraged to think of the mousetrap car's movement in terms of kinetic and potential energy, the use of levers and pulleys to produce motion and the effect of friction on the car's performance. Throughout this and other stages, there was a continual classroom presence by the STEP Fellow. This allowed the students easy access and a convenient feedback mechanism for the teacher. The teacher's insight on the potential pitfalls and possible lack of building materials and space outside of class led to the dedication of one class period for building the mousetrap cars.

In the second stage of the competition, a simple working model demonstrating the ability to produce forward motion with the mousetrap was required. This was included to force the students to develop a working prototype well before the due date of the final project. It was also used as an opportunity for the students who weren't comfortable with or were having difficulty constructing a working device to get feedback and ideas from other students. Following the display of their prototypes, the students briefly presented the reasoning behind their design choices. Even though the students were on different teams, this encouraged dialogue and created a cooperative environment.

The final stage was the actual competition. The goal was to design a car that would travel 20 feet and stop on a target. Before the running of the car, the team briefly presented their final design, highlighted what they felt were the critical design components of the car and made predictions on the upcoming performance. Only a small portion of the final grade was based on the actual performance. The majority of the grade was based on the oral presentation and final report. The final report was a more formal accounting of the information presented on competition day and included a section on the use of the physics concepts in the design process. The oral presentation and written report were required to encourage the development of the communication skills.

Going beyond the High School
In an effort to increase the likelihood of student participation in a competition with Georgia Tech students and develop the skills necessary for the competition, the high school students were presented with opportunities for participation in several local high school competitions. A group of Cedar Grove students participated in the annual High School Lego Robot Challenge Competition sponsored by the Georgia Tech RoboJackets and the School of Mechanical Engineering at Georgia Tech. This three-day event focuses on students with no previous programming experience. Using Lego MindStorm kits, students from six Atlanta-area high schools learned the fundamentals of programming and machine construction. The three-member student team from Cedar Grove won the final competition. The students participating in the competition enjoyed it so much that two MindStorm kits were purchased for use in the school.

A three-member student team was also formed to participate in the SECME (formerly the Southeastern Consortium for Minorities in Engineering) regional design competition. In this particular mousetrap car competition, the goal is maximum distance with penalties for weight and length. This forces the team to make a series of design trade-offs and carefully consider construction materials. The team final score was based on a written report, an oral presentation of the design and the performance of the design. This, again, encourages the development and demonstrates the importance of written and oral communication skills.

Expanding the Footprint
Using the Lego MindStorm kits as a start-up platform, an after school Robotics Club was established at the high school. This allowed us to attract students outside of the Physics classes. The meetings were kept fairly informal. There were tutorials on programming, often from a student already familiar with the MindStorm kits, but the students were allowed to build or program as they pleased. The majority of the students at these sessions had little or no experience building or programming, so the emphasis was placed on overcoming any fears or apprehensions of working with the components and reducing frustrations when problems occurred. However, as the semester progressed, the students became more independent and required less hands-on guidance.

ME2110 Competition
A team of volunteers from the Physics classes and the Robotics Club regulars worked on the ME 2110 competition design. These students learned to program the controller box by completing the same programming assignments used in the Georgia Tech course. They used the design tools

taught in the class to help develop design alternatives. In addition to building before school and after school during the Robotics Club meetings, the students made two trips to Georgia Tech on weekends to test their designs on the actual track along with the regular ME2110 students. Building materials were purchased with the help of a supply fund provided by the STEP program. Initially, there were eight students working on the design. As the semester progressed, the team ultimately decreased to the three members.

The high school students were full participants in the Georgia Tech competition and subject to the same rules and restrictions as any other entry. Figure 1 shows an example competition in the Spring 2004 contest. In this competition, the students were required to construct machines to perform a mission to Mars. Tasks included collecting Mars samples (candy bars), delivering a probe and avoiding space debris. See the Appendix for a more detailed description of the competition and design requirements. The Cedar Grove machine made it to the third round of the five round tournament. After completing the competition and performing better than they originally expected, the high school students were excited about the next year's competition.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 1: Spring 2004 ME 2110 Competition.

3.2 Year-Two Activities

The incremental approach is being utilized again for a second year, with anticipated growth in participation in future competitions.

Mousetrap Car Competition

A mousetrap car competition was again conducted during the fall semester of the second year at Cedar Grove High School. The objective of the competition remained the same, to design a car powered only by a mousetrap that would travel a predetermined distance. Students were separated into groups of two, and the competition was divided into several stages. Several partial sessions of class were devoted to concept development. In addition, a trial competition was held one week prior to the final. The goal of this trial was to force the students into an iterative design process. Many students did use the practice session to their advantage, and returned the following week with better cars for the final competition. The final designs are shown in Figure 2.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 2: Year Two Mousetrap Cars.

In addition to designing and building the mousetrap cars, the students were required to write a report detailing their project. The reports were due the week following the competition, and served as a tool to introduce many of the technical writing ideas that are taught in the Georgia Tech course. The exercise also served to reinforce the importance of writing skills, one of the major objectives of the second year STEP fellow. In addition to a written report, the students were asked to give a short oral presentation prior to their turn in the competition. This followed another emphasis of the Georgia Tech course, effective presentation of ideas, while forcing the students to use the physics vocabulary that they had developed in class.

Another attempt to expose the students to designing with multiple objectives, and the evaluation of designs, was the grading scheme used for the project. The students were allowed to select what percentage of their grade for the project was determined by the performance of their cars, and what percentage was determined by their reports. The students could choose a percentage between twenty-five and seventy-five for each, totaling to one hundred percent. This idea was introduced as being analogous to the "business" side of the project, similar to choosing the proper appropriation of resources for a product launch. The goal of this approach was to attract the interest of those students who may not have been greatly interested in the engineering parts of the project.

Robotics Club

The Robotics Club is another activity that was continued the second year. Several students from the first year continued participation, and several others joined. A major project for the club was building a Lego Mindstorm car to compete in the Physics Class's mousetrap car competition. This exercise helped to introduce the Lego Mindstorm kit to the new members, and as a refresher for the senior members of the club. Additional goals of the Lego Mindstorm car were to introduce the Physics class to robotics and to increase interest in the club. While the students were, in general, impressed with the car, unfortunately no new membership resulted.

4. Course Description

Critical factors in gaining student participation in extra-curricular activities range from student interest, to perceived applicability to future goals, to the "WOW" factor. Given that the area of mechatronics combines several disciplines, projects in this field can appeal to students with a variety of backgrounds and interest. An introductory mechanical design course at Georgia Tech, ME2110: Creative Decisions and Designs, provides and excellent forum for teaching fundamental mechatronics concepts [1]. The students can learn the traditional mechanical design curriculum, planning and evaluation tools, functional decomposition, machining and report writing. Since the final product is in the novel and exciting field of mechatronics, the design is both rewarding and stimulating. The predominate belief is that a student must be well versed in mechanical design, electronics and programming in order to handle mechatronics. While this is certainly true for advanced issues, very basic mechatronics concepts can be grasped by most engineering undergraduates. This course was targeted because of the excitement it creates in the students and the broad spectrum of skills needed.

5. Lessons Learned

The Cedar Grove High School-Georgia Tech ME 2110 partnership has yielded some promising results. The high school students and teacher have been exposed to new concepts and new ways of presenting and learning old concepts. The STEP Fellows have a greater appreciation of the effort needed to construct a high school curriculum or implement a new project. The key lessons learned from the partnerships are listed below.

- For students unaccustomed to hands-on projects, there is a considerable amount of consternation during the initial phases of construction. One of the hardest things to do is to *start* building. If the initial assignment is easily attainable, or can be completed during class time while help is around, the remainder of the construction process will be more manageable.

- The students in both the year one and year two mousetrap car competitions had trouble integrating the language of physics into their oral presentations and written reports. We were unable to determine if this difficulty was a result of not understanding the concepts, not understanding how they apply to the mousetrap car, or a lack of comfort with the terminology.

- The high school teachers are a great source of information. Since they know the students and the students capabilities best, consult them when developing lecture modules or projects.

- "Face time" is imperative. Spend as much time as possible interacting with the students and easing them along during the process. This helps ease any anxiety and creates an environment were the students feel comfortable asking questions.

- Show the school that you're seeking a long-term commitment. The partnership cannot be successful without the support of the administration and teachers.

- Patience. There is a significant difference in the maturity of high school juniors and seniors and freshmen or sophomore undergraduate. Also, high school students face significantly different time constraints than undergraduates.

6. Conclusions

A partnership between Cedar Grove High School and the Georgia Institute of Technology has been formed. One of the facets of the partnership is the participation of high school students in a sophomore-level Mechanical Engineering mechatronics design competition. A significant time commitment by Georgia Tech STEP Fellows was needed in order for this partnership to be successful. However, once the partnership was established, it was relatively easy to maintain.

Acknowledgments

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References

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Appendix

The following is the contest description given to the Georgia Tech students enrolled in ME 2110 during the Spring of 2004.

Given the current rover missions to Mars and President Bush's directive for the United States to start manned exploration of Mars, there is a good chance that some of you will work as engineers on a mission to Mars. To help prepare you for your future career, you will develop a machine that performs some of the basic functions of such a spacecraft. Figure A1 shows the simulated space environment in which your device will perform. The area is a hexagon divided into three zones, one of which will be assigned to your team. Each zone consists partly of a home zone and partly of a gravity zone. At the center is Mars. It rotates along with its two moons, Deimos and Phobos. These orbiting moons are a menace to your device. If you come into contact with them, they will likely take your machine along with them. Your device should try to perform the following four tasks:

1. **Collect Mars Samples.**
   On the surface of Mars will be various pieces of Mars®. Your machine should collect them and return them into your home zone. Each full size Mars® Bar that is returned completely within your home zone will score 5 points, any Fun-Sized Mars® Bar that are returned completely within your home zone will score 2 points.
2. **Deliver Probe.**
   You will be given a probe in the form of a plastic egg. Your machine should deposit the probe in Olympus Mons – the huge shield volcano in the center. If your probe is deposited completely within the volcano crater you will receive 20 points.
3. **Avoid Space Debris.**
   A random distribution of space debris (balls of tin foil and tin cans) will be within your home zone. Your machine should clear away the debris. Each piece of debris left in your home zone will deduct 1 point from your score.
4. **Return Home.**
   When you have completed your tasks, your machine should return home. If your entire machine (except the probe) leaves the gravity zone, then your score will be doubled or you will receive +10 points, whichever is greater.

The space environment is an equilateral hexagon having 4.5-foot-long sides constructed by 2X4 lumber over 1/2 in. plywood, as shown in Figure A2. These 2X4's are oriented such that their height is 2 inches (actually about 1.5) around the perimeter of the area. They are stacked on top of the 1/2 in. plywood base, so the top of the area perimeter is approximately 2 inches above ground. The area is divided into 3 equal size zones.

At the center is Mars. The planet is approximately 22 inches in diameter. When the contest begins, Mars and its moons will start to rotate. There will be a lip around the outer edge, so that the Mars samples do not fall off. The height of the lip will be approximately 1 inch.

A side view of Mars is shown in Figure A3. Note that the two moons will not be directly over each other, but displaced by a large angle as shown by the overhead view in Figures A1 and A2. All dimensions are approximate. Your device should be robust to these uncertainties.

Your solution should not be expensive or complicated. To limit the expense and complexity of your design, you are permitted to use energy only from the computer supplied to you, as well as energy from 5 mousetraps and gravity. Your team will be provided with a set of actuators including: 2 DC motors, 2 stepper motors, and 2 solenoids. No other actuators may be driven by the computer. The computer also powers the sensors which are: an IR range detector, several micro-switches, and a flex sensor. You may purchase additional building materials and sensors as long as your budget remains under $50.

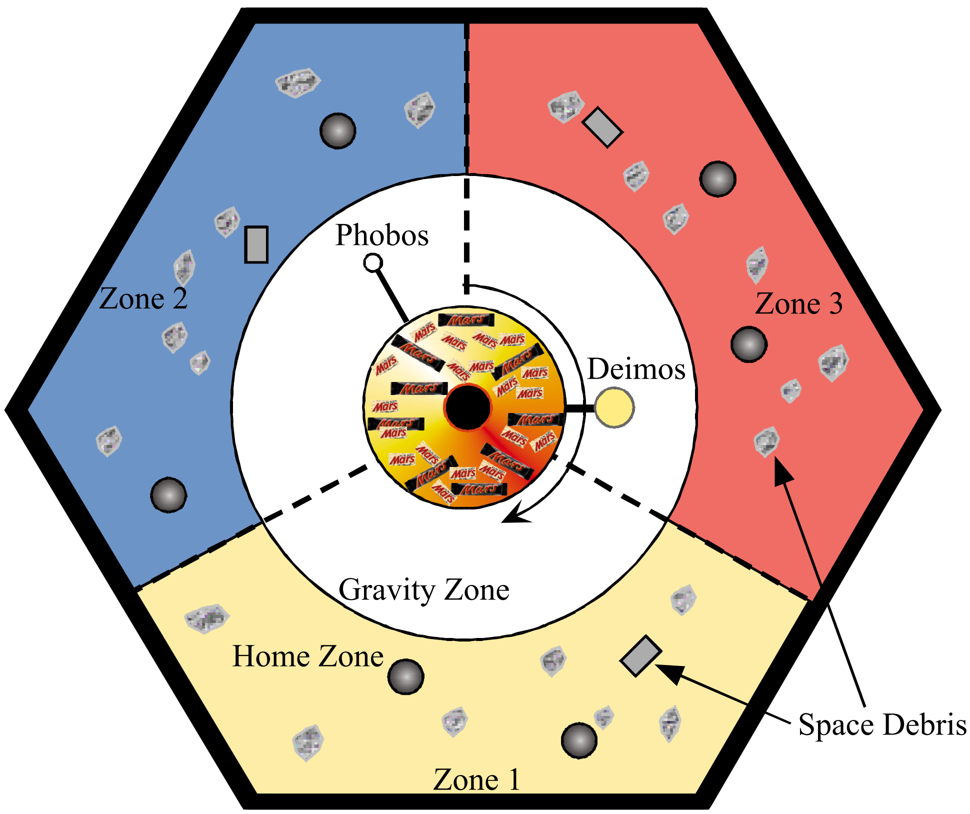

Figure A1: Space Environment.

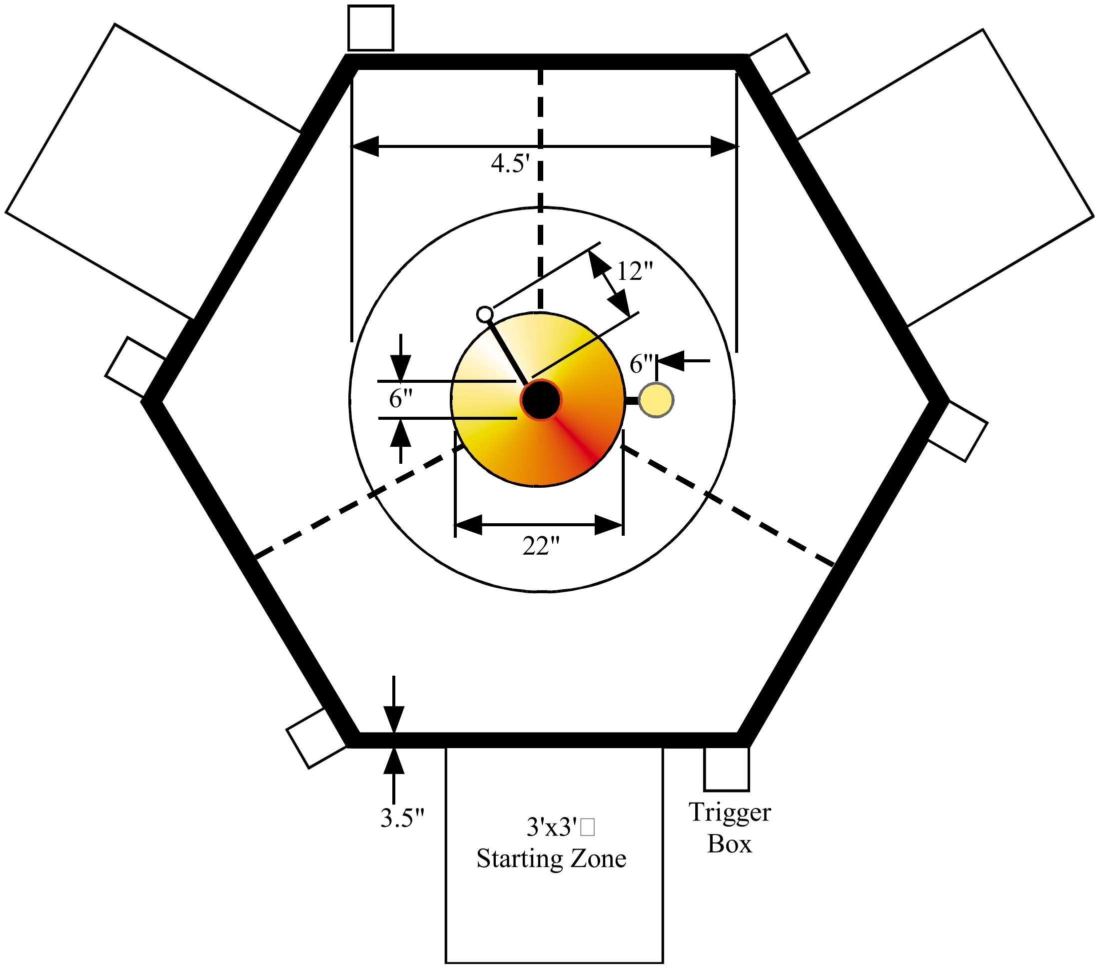

Figure A2: Approximate Dimensions of Space Environment.

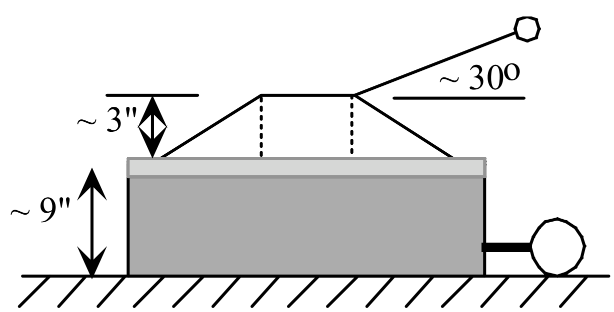

Figure A3: Side View of Mars.

BIOGRAPHICAL INFORMATION

Michael Robertson
Mr. Michael Robertson is a Mechanical Engineering graduate student at Georgia Institute of Technology and 2003-2004 STEP Fellow. Michael received his Bachelor of Science in

Mechanical Engineering from Florida A&M University and his Master of Science in Mechanical Engineering from Georgia Institute of Technology. His current area of research is command generation and control of flexible systems and tethered satellites.

Joshua Vaughan
Mr. Joshua Vaughan is a Mechanical Engineering graduate student at Georgia Institute of Technology and 2004-2005 STEP Fellow. Joshua received his Bachelor's Degree in Physics and Applied Mathematics from Hampden-Sydney College. His current area of research is advanced seating systems with interest in both automotive and wheelchair applications.

William Singhose
Dr. William Singhose is an Assistant Professor in the Woodruff School of Mechanical Engineering at Georgia Institute of Technology. He received a Ph.D. from the Massachusetts Institute of Technology. His primary research interests are spacecraft control, sway reduction in cranes, control of flexible structures, and active seat technology.

Michael Pastirik
Mr. Michael A. Pastirik is a science teacher at Cedar Grove High School. Michael has been a teacher for twenty-four years in public and private schools. Presently, his teaching responsibilities include the teaching of Advanced Physics, AP Chemistry, and ESOL (English as a Second Language). Michael received his undergraduate degree in Biology at SUNY Oneonta, and his Masters Degree in Science Education at Georgia State University.

Marion Usselman
Dr. Marion C. Usselman is a Research Scientist at the Center for Education Integrating Science, Mathematics and Computing (CEISMC) at Georgia Institute of Technology. Marion received her Ph.D. in biophysics from Johns Hopkins University and has taught in the Biology Department at the University of North Carolina, Charlotte. She focuses on equity issues in education and K-12 educational reform. Marion is co-PI of the STEP NSF grant.

Donna Llewellyn
Dr. Donna C. Llewellyn is the Director of the Center for the Enhancement of Teaching and Learning (CETL) and an adjunct associate professor in Industrial and Systems Engineering at Georgia Institute of Technology. Her current areas of research are in equity of engineering education and assessment of instruction. Donna is the PI of the STEP NSF Grant.