

AC 2008-882: A RACE CAR DESIGN-BUILD-TEST PROJECT FOR LOW INCOME, FIRST GENERATION PRE-COLLEGE STUDENTS

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Abstract

There is much interest in developing curricula to help K-12 students understand what an engineer does in order to further interest in engineering¹. Students have misconceptions on what engineers do and how they impact society. This paper presents results of how a small group (N=12) of high school junior's attitudes towards engineering changed based on an introduction to electrical engineering summer course where students built and tested a computer controlled radio control (RC) car. The students—the first generation to consider attending college—were drawn from low-income households in the six-county area surrounding an Oklahoma State University. The purpose of the six week intervention, part of a campus-wide Upward Bound program was to give students a realistic view of engineering as a career option.

To evaluate the effectiveness of the intervention two assessments were used. A pre-post *Draw an Engineer*¹ with a written component was used to measure perceptions of engineers. More students self-identified themselves as engineers following the intervention. Overall the draw an engineer shows an increased understanding of what is involved in engineering. Post-intervention interviews also examined students' changes in attitudes about engineering. Interview data indicates increases in student intentions to pursue engineering and that the format of the intervention gave students a realistic view of engineering.

Introduction

The Upward Bound program is one of six federal TRIO educational outreach programs². The program targets high school students from low-income families or from families in which neither parent attended college. The stated goal of the federal Upward Bound program “is to increase the rate at which participants complete secondary education and enroll in and graduate from institutions of postsecondary education.”²

At Oklahoma State University, the Upward Bound program offers a pre-college summer experience. For six weeks over the summer students live on campus during the week for a variety of academic, cultural and social activities. Students attend classes modeled after college courses. Students are encouraged to attend the program for consecutive years and Upward Bound offers courses aimed at the different grade levels of the students. Courses are taught by college faculty and graduate students. Following the summer program mentors—college students and faculty—tutor and counsel participating students at their schools in the surrounding community. Following the summer program the progress of pre-college students is tracked to help them prepare for college.

For three years of this program no engineering courses were offered to students. This paper reports on the first iteration of an engineering course offered to students in the fourth year of the Upward Bound Math and Science program. The sample reported here consisted of N = 12 students. The sample was not diverse ethnically; only one student was not white. Nine of the

twelve participants were women. One student was deaf, and had a translator in the classroom. The sample participated in a mini-course simply titled “Engineering”. The course goals for the first iteration of the Upward Bound program were to 1) generate interest in engineering as a career path, 2) address any misconceptions of engineering and engineering careers held by students, and 3) give students an opportunity to apply the math and science knowledge gained in other Upward Bound courses. These objectives are similar to other pre-college programs reported in the literature³⁻⁸. A project based learning approach⁹⁻¹² was used to give students hands-on experiences in engineering. To this end, four teams of three students each assembled a custom designed radio control (RC) car with customizable options which they entered in a series of competitions during the final week of the course. Similar projects, many involving robots, have been used previously to teach novice engineers engineering concepts¹³⁻¹⁹. The course model and structure are described later.

To assess changes to how students view engineering and identify initial misconceptions two different evaluation metrics were used in a pre-post format at the beginning and end of the course. The first, the *Draw an Engineer Test*¹ simply asks the students to draw an engineer on a piece of paper. Second, students were asked to write five words that describe an engineer.

Description of the Engineering Design Project

Since a project-based approach was used, it is necessary to first describe the project to provide needed context to understand the format and structure of the six week summer intervention. Prior to the beginning of the summer course, two electrical engineering graduate students designed a custom radio control (RC) car. The design goals of the car were to have a system simple enough for high school students to build during the 11 contact hours per week for six weeks. The design project reflects, to the extent possible, as many possible steps of the engineering design cycle²⁰. A critical criterion was developing an accessible design project that allowed students to make choices and also to provide some design constraints. It was decided that design constraints should be implemented in software rather than hardware in order to keep the time-consuming hardware design and project cost minimal.

To this end a control board for a commercial 1/10th scale radio control car was designed based on a PIC16F876A microcontroller. Commercial RC model cars were used as the motion platform due to their broad availability, relatively low cost (~ \$US 150 per car), ease of interfacing, and the ease of changing the car’s appearance without making any substantial changes to the hardware. A large variety of different body styles can be attached to a given chassis and power-train. Cars were controlled by a laptop computer through a 2.4 GHz wireless connection. Each car used LEDs for headlights, brake lights, and turn signals which could be controlled through the computer. An integrated sound recorder/amplifier integrated circuit and speaker enabled the cars to play recorded sounds on command. The cars were also equipped with infrared (IR) emitters and detectors allowing the cars to “shoot” each other at close range. All cars built by students were equipped with these hardware options.

To provide constraints to the design problem “design options” on car performance were chosen by participating students. The options chosen were programmed into the microcontroller firmware when the cars were completed and could be easily changed by reprogramming the

microcontroller using software on a laptop. Student teams were informed they had to choose design options to maximize performance of their car in six different competitions. The competitions were performed in the last week of the summer intervention and included:

- 1) Best looking car: judged by a panel of instructors.
- 2) Drag race: a straight track bracket style race.
- 3) Slalom course: weaving through cones to test handling
- 4) Obstacle course: timed navigation of a twisting course with walls and a bridge.
- 5) Indy 500: a long multi-lap race with pit stops.
- 6) Mario-kart rally: similar to the Indy 500 but with the IR cannons enabled.

The interviews were conducted by a professor not associated with the course so that the instructors biases were not seen in the responses.

The six week course was divided into three phases that reflect a simplified engineering design cycle: project management, building, and debugging and redesign. The 12 students were divided into four teams of three students each by gender- three female teams and one all-male team. Dividing teams by gender was chosen to minimize distractions that were reported among for mixed gender teams by the program directors of Upward Bound. During the project management phase of the course active learning exercises were used to build team cohesion and teach students the engineering design cycle. Students participated in three teamwork exercises: *Six Thinking Hats*²¹ to acquaint students with how different individuals approach problem solving differently, the NASA moon survival challenge that forces students to make choices in solving a problem, and a card game called “Werewolves and Peasants” designed to introduce students to ill-defined problem solving scenarios in which there is no single correct answer. These activities were also meant to build teamwork skills and familiarity among the students and have been used successfully in team-based undergraduate engineering courses in the degree program at Oklahoma State University. Active learning exercises were also used to teach students the engineering design process²⁰. Students created a block diagram and work breakdown structure for a bicycle and also constructed Gantt charts. It was hypothesized that these exercises would introduce students to the experience of breaking down ideas and tasks into their components and creating timelines for accomplishing tasks. After practicing and receiving feedback from the instructors, students were asked to create a block diagram, Gantt chart and work breakdown structure for the building phase of the course. The first phase also collected assessment data by giving the *Draw an Engineer* test and asking students to provide five words describing engineers.

In the building phase of the course the students were asked to perform every aspect in the assembly of their team’s car. The building phase took the majority of the six weeks of the summer intervention. Students were given the circuit diagram of the control board, the instructions and parts from the commercial RC car kits, and the necessary tools and parts. Fabrication of each team’s car involved three distinct technical tasks that required specialized training: PCB layout in CAD software, PCB production using a mill and component soldering. The jigsaw method²² was used in training students. One student from each team learned electronic CAD, PC board fabrication, and soldering then brought these skills back to their team. A cognitive apprentice model was used in training students where a task was first modeled by experts (the graduate students) followed by students independently completing a simple task. All students in a team received training in each of the three fabrication skills and the team chose

roles for each team member in building their car. In other words, one student on each team was a content expert in each of the three fabrications skills.

The fabrication steps undertaken by the student teams included assembling the car chassis and powertrain kit, design of a printed circuit board (PCB) layout in CAD software that adhered to accepted electronic fabrication guidelines, create a printed circuit board using a computer controlled mill, then solder all the electrical components in place. Student teams worked with the instructors to debug errors in the control boards. This one-on-one time was used to teach students basics of electronic circuits.

This format proved to be somewhat problematic in practice. Since the fabrication tasks are consecutive—i.e. the CAD design needs to be done before the printed circuit board can be created—many students on a team had too much free time. The instructors initially assumed that this free time would be filled assembling the car kit and designing a paint scheme for the car. These tasks were not as time consuming as the actual control board fabrication however. Initially there were three graduate student instructors assigned to the course, one for each of the fabrication steps, but one instructor was not available and management of the course was problematic in this first iteration and may affect learning outcomes.

Once the teams' cars were assembled they were given a budget to spend on options for their car. These options were then programmed into the car altering the car's performance depending on the options they chose.

Also being a first iteration of a design, the custom RC car had some functionality issues taking away from the time the students had to compete. A large portion of the time during the final week was spent setting up the race course while numerous electrical connectivity issues were repaired on the students' cars. In addition, the difficulty of controlling the car from a third-person perspective effectively nullified the effect the different options had on the outcome of the races. While the options clearly affected the turning radius and throttle action of the car, the difficulty of basic tasks such as maintaining a straight path sent most cars careening into walls causing more connectivity issues.

Despite these issues, the students completed the drag race and obstacle course competitions and designed posters advertising their team's work. Eight of the students also completed post-intervention surveys asking about their experiences and views of engineering.

Results

Following the summer Upward Bound session pre and post data was analyzed to determine if the three learning goals were achieved. Draw an Engineer exercises were analyzed qualitatively by looking for different elements in the drawings submitted by students. The preliminary inspections of student drawing yielded nine different categories on which pre-post drawing were compared. These include:

- Male/female: if the sex of the figure is obvious, i.e.: short hair or masculine figure for male and long hair, pony tails or a dress for female.

- Self identification: some students wrote “me” or “me as an engineer” with an arrow pointing to the figure they drew.
- Tool or instrument use: if the person drawn is using a basic tool such as a screwdriver, wrench or calculator.
- Working on a car: if the person is performing maintenance on an automobile. Since car repair is not a common task for an engineer, this can be used to show a lack of familiarity with engineering¹.
- Computer: if the student drew a computer.
- House or building: if the student included a structure in their drawing.
- Smiling/frowning: if the student drew the engineer obviously smiling or frowning.

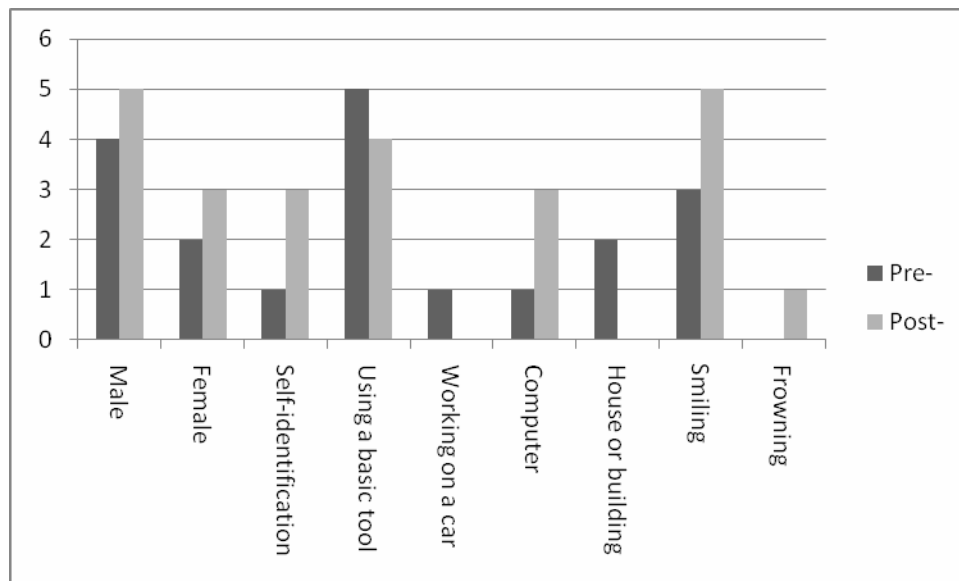


Figure 1: bar chart of the data from the Draw an Engineer Test.

Figure 1 shows the results of visually inspecting each student’s drawing of an engineer for nine different criteria. Complete data was only available from eleven of the twelve students. In addition, three students in the post-test drew activities from the course such as soldering or controlling the car. Two of those students also self-identified. No drawings seemed to depict teamwork or working with others. As can be seen from figure 1 more students self identified with engineering in the post test than the pre test. The post test also showed more students had an emotional tie to engineering than in the pre test.

Figure 2 shows the results of categorizing the five words describing an engineer provided by each student.

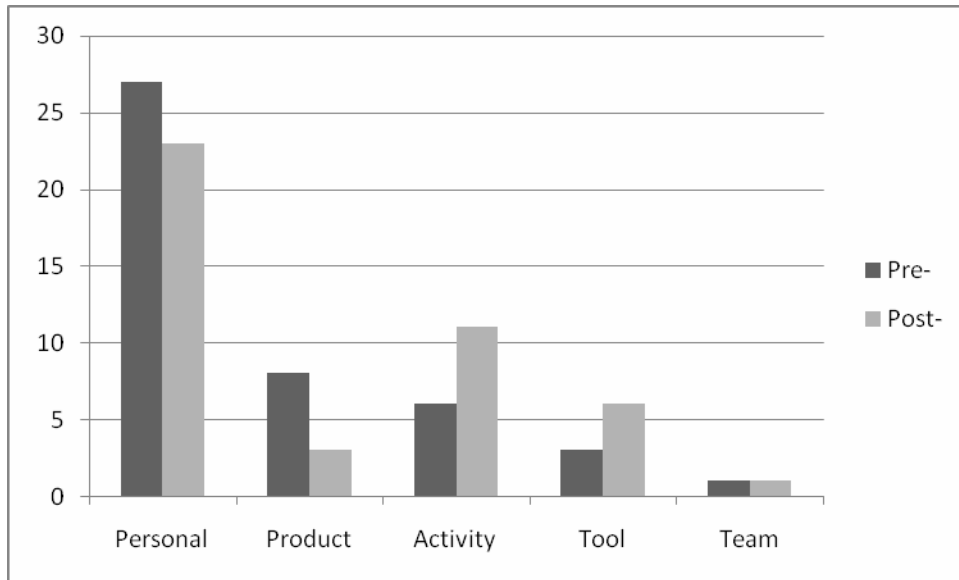


Figure 2: the number of words fitting into the categories described below.

- Personal: describing a person or a personal trait i.e.: analytical, creative, smart.
- Product: a product of engineering i.e.: cars, motors, electronics.
- Activity: describing an activity of engineers i.e.: hands on, boring, build.
- Tool: a tool engineers use i.e.: computer, numbers, wrench.
- Team: words describing team qualities or activities. The only qualifying words were helpful and dependable.
- Additionally in the post-test, eight words described activities from the course i.e.: soldering, milling and wiring.

All of the example words shown above are actual words from the students. Comparing the results, the number of personal words and product related words decreased while the number of activity related words and tools increased. A very small number of words were related to teamwork or interpersonal activities.

Post-intervention interviews with students were performed at the end of the summer program. Eight of the twelve students were interviewed. Six questions were asked during the interview; four questions sought to get information on students' perceptions of engineering while two questions were used for project evaluation. Overall the interviews supported the conclusions drawn from the Draw an Engineering and writing assignments.

When asked to define engineering only one student was unable to do so. Responses from other students were focused around themes of solving problems, technology, and the application of science and math. When asked what they had learned about engineering half of the respondents comments centered around the theme that engineering was both challenging and rewarding. "...shouldn't be afraid to take on challenges." Another theme that emerged from half the responses was that of a need for management and organization when performing technical work. As one respondent put it, "...[you need to] know what you are doing." The level of challenge and need for organization did not seem to deter students. When asked if they had considered

engineering as a career option before the course only one student responded affirmatively. After the six week program five participants were considering engineering. It is important to note that interviews were performed at the end of the intervention during a demonstration of team's projects and this may have biased responses. The interviews were conducted by an independent evaluator.

Conclusions

Using the data acquired in this study it is difficult to conclude that the students had developed a clear understanding of engineering. Despite spending the majority of the course time working as a team, the students did not seem to incorporate that experience into their understanding of engineering. Nor did they make any mention of the project management activities from early in the course. However the one indication of an unrealistic understanding, the depiction of car repair, was only seen in the pre-test.

There is also some evidence that seems to indicate the students developed a more personal understanding of engineering. First, more students drew themselves as the engineer in their drawing on the post-test than the pre-test. Also in the post-test several students included concepts or activities from their own experience to describe engineering.

The course did generate an increase in interest in engineering among the participating students. All of the students seemed to enjoy the experience and four stated they were considering engineering as a career path due to taking the course.

Future Work

Due to the size of the course the conclusions are based on this pilot course. This course will be repeated with students that are of different age groups and larger sizes in order to get more conclusive evidence that this is a good intervention.

Since the initial six week engineering course this project has evolved. Instead of making design decisions on a budget to try to win competitions, students use the car as a mobile sensor platform. The car is no longer manually controlled, but is instead loaded with a prewritten list of commands that are executed at specified times. As this program runs start to finish, the car records readings from an accelerometer and a wheel motion sensor allowing measurement of the acceleration the car undergoes and the distance it travels. This data can then be analyzed to show a number of concepts relating to physics, calculus and engineering.

Already this car has been used in an introductory engineering course for college freshmen to demonstrate working with real data. The final project was to design a crash barrier out of manila folders and Styrofoam cups to attenuate the deceleration of the car when it impacts a solid wall. The recorded acceleration data from the crash was analyzed to see which team's barrier was most effective.

The Upward Bound Math and Science program at Oklahoma State University plans to hold the same engineering course for a second time during their six week program in 2008. Prior to this,

a more extensive review of similar programs and studies needs to be conducted so students can be evaluated using a greater number of procedures to determine interest in and understanding of engineering.

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