An Electrical Engineering Summer Academy for Middle School and High School Students

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Abstract

The Electrical Engineering Summer Academy for Pre-College Students was held at the University of Tulsa from June 11th through June 15th, 2007. Of the 20 students accepted, 19 participated, along with four high school teachers. Seventeen students and two teachers were from Tulsa County and surroundings, with two students and two teachers from distant counties. The students and teachers participated in team-building, professional development, and technical activities designed to teach about the engineering profession and the field of electrical engineering. Activities included laboratories in electrical circuits, designing an electric car, soldering, a field trip, and discussion about ethics. Students worked in two and four-person teams, and made presentations on their experiences.

The academy was evaluated using formal assessment instruments and faculty observations. Each of the individual activities attained an overall rating of at least 4 on a scale of 1 to 5, with most activities rated at 4.5 or greater. A formal evaluation of the entire academy revealed ratings of 4.5 or greater out of 5 on most aspects of the academy, though some areas indicated a need for improvement, such as clarity of written materials and the availability of additional material for advanced students who finished early. Additional assessment examined whether the students acquired knowledge during the academy. Improvement in knowledge was demonstrated on over 50% of the survey questions. The students also demonstrated improvements in teamwork skills. A number of areas for improvement have been identified, and changes are in place for future sessions of the Academy, including better materials, modified activities, and a more formal training process for the teachers.

Introduction

Employment opportunities in science and engineering occupations are expected to increase through the end of the decade. However, there has been a declining trend in enrollment in undergraduate science and engineering majors at U.S. universities. In fact, the U.S. trails many other industrialized nations in the percentage of bachelor's degrees in science and engineering[1]. A contributing factor to this problem is that engineering lacks a formal presence in K-12 education. As a result, many qualified students are unaware of career opportunities in science and engineering, and thus fail to pursue technical majors in college[2].

To address the need for the exposure of students to the career of engineering, and particularly electrical engineering, we developed an Electrical Engineering Summer Academy program at the University of Tulsa. The objective of our program is to make students aware of engineering career opportunities through hands-on design projects, seminars, and tours of local companies. In addition, high school teachers will receive training and assist the investigators with the academy's classroom activities. The program is designed to encourage and support the teachers in implementing academy exercises within the teachers' classroom during the regular school year. The overall goal is to attract more Oklahoma students into engineering study to help meet Oklahoma technical employer needs. By exposing students to engineering through hands-on experience and projects, the academy will help illustrate the need for students to develop math and science skills to tackle challenging and interesting engineering problems.

In this paper, we present a description of the activities developed to achieve the goals of the program and provide results from formal and informal evaluations on the effectiveness of the program in meeting its goals for the session held in June of 2007. We also discuss changes planned to the program as a result of the evaluations for the subsequent summer sessions.

Description of the Program and Activities

Overview

The Electrical Engineering Summer Academy is a five-day program designed to serve local junior high and high school students. The structure of this program is based on reports of successful summer engineering academies at other universities[3-5]. A review of these programs revealed several key ingredients for successfully engaging and teaching high school students. These include an emphasis on hands-on activities and team projects with minimal lectures, and field trips to local industries to illustrate applications of concepts learned in program. In addition to developing technical skills, it is important for prospective engineers to develop professional skills. The Accreditation Board for Engineering and Technology (ABET) has identified desirable professional skills for engineering graduates[6]. These include the ability to function on multi-disciplinary teams, an understanding of professional and ethical responsibility, and the ability to communicate effectively. Therefore, to properly educate students about the engineering field, our program incorporates both technical and professional skills.

The general schedule of the Academy is shown in Figure 1. The first part of the week includes background activities designed to familiarize the students with basic concepts relevant to all engineering disciplines as well as those concepts specific to electrical engineering. The opening activities focus on the basic principles of team building, communication, and engineering design. The next group of activities provides the students with basic skills and knowledge in electrical engineering, including constructing a circuit, basic measurements, digital logic, logic gates, soldering, and basic circuit components such as capacitors, resistors, batteries, and switches. The middle of the week focuses on integrating knowledge and information gained in the initial activities with a little new knowledge to design and construct a more sophisticated circuit with a more practical application. In addition to these activities, speakers from industry and education meet with the students and talk about their own careers, the preparation needed to become an engineer, and career opportunities for engineers. The end of the week again focuses on more general engineering aspects, and includes activities in engineering ethics, career development, a field trip to an active engineering site, and the development of a presentation on one aspect of the Academy. The presentation is made to the faculty and parents at the ending banquet.

For each topic, the scientific background and the basics are introduced by a brief lecture and significant hands-on exploration. The hands-on laboratory experience is used to reinforce and apply the concepts while making the material more exciting and relevant, as the students become active participants. For each topic the instructor presents basic information for the first concept, then students perform a lab exercise based on this information. This process is repeated for each topic concept, to provide hands-on experience with minimal lecturing. Each exercise builds on the previous one, leading to a complete electrical system by the end. To increase student interest in the projects, design competitions related to the topics are held that expose students to engineering decision-making based on criteria such as cost, environment, and reliability. All participants will receive material to support the concepts taught, and build items to keep. All of the exercises reinforce the mathematics and physics concepts that appear in the core high school curriculum.

All students work in teams of at least two students. These teams emphasize the importance of interpersonal skills and the improved output achieved when people combine their talents and strengths. Each student is assigned specific responsibilities within the team. The roles may be rotated. This team structure ensures that all students participate in activities, and increases organization both in and out of the classroom.

	Monday	Tuesday	Wednesday	Thursday	Friday
9 AM to 12 PM	Intro Engineering Principles	Circuits Project	Integration Project	Field trip	Professional skills workshop
12 PM – 1 PM	Lunch Free Explore	Lunch Free Explore	Lunch Free Explore	Lunch Free Explore	Event
1PM to 4 PM	Speaker Circuits Lab	Speaker Digital logic lab & project	Speaker Integration Project	Engineering careers/ethics workshop	Adjourn
4 PM	Adjourn	Adjourn	Adjourn	Adjourn	

Figure 1. Summer academy schedule.

To break up the day, students will also participate in free exploration activities. Examples include a game or contest with a science orientation (such as orienteering on the campus), further exploration of an activity or topic presented earlier, and a brief educational activity following up on a class session.

Three to four pre-college science and math teachers participate in and assist with the program. The teachers are expected to attend an information and training session the week prior to the academy to provide basic instruction on the concepts and activities comprising the academy. The teachers assist the academy directors with methods to ensure student involvement and attention during activities. After the academy concludes, the directors meet with the teachers to evaluate the program and discuss changes for the following year. The directors hope to work with the teachers to introduce elements of the academy into their classes during the school year.

The teachers' involvement becomes an enrichment and sabbatical-type experience for these teachers, as well as a way to reach more precollege students.

Examples of Specific Activities

Here we present brief descriptions of some of the activities that were part of the Academy in the summer of 2007. The examples cover team-building, professional development, and technical aspects of the Academy program. The two technical activities were chosen to demonstrate how activities were designed to build upon each other to reinforce the idea of building on basic concepts to construct more complicated systems for real applications.

<u>Communication and Team Building:</u> The purpose of this activity was to explore the various ways that groups of people communicate and work together to arrive at a common goal. Students were randomly placed into teams of four students for this activity. Initially, each team had to build four objects selected by the instructor using a set of K'Nex. Each construction project was accompanied by conditions that challenged the students to find different ways to effectively communicate information, such as blindfolding the constructor or allowing only one person to see the object under construction.

After the four objects were built, each team was asked to build a robot to compete in a sumo-wrestling tournament. The students received no instruction on how to build the robot. Instead, each team had to analyze, experiment, and collaborate to arrive at a solution. The robots competed and the winning team received an award certificate at the final banquet.

<u>Electrical Circuits:</u> The students worked through some basic concepts of circuits that were fundamental to many of the later activities. The students learned the basic laws of current, voltage, resistance, and power through experimentation and some lecture. Ohm's law was taught using a voltmeter, resistor and power supply. Power ratings were investigated by finding the point where a component overheated (i.e. caught on fire for full dramatic effect). The students also learned the resistor color code, how to correctly wire a light-emitting diode (LED), and how to construct circuits on a breadboard.

<u>Electric Car:</u> The students explored the concept of resistor-capacitor (RC) circuits with respect to the application of powering an electric car. This activity directly applied much of the knowledge from the Electrical Circuits activity and asked the student to build upon that knowledge. Each team built a small K'Nex car for testing purposes. The students then studied how quickly the capacitor charged through a circuit and a power supply. The students attached the charged capacitor to their cars and studied similar aspect of discharging the capacitor. The results were used to address concepts of series and parallel capacitors and resistors. The students then competed to see whose car would travel the farthest on a single charge.

<u>Ethics Challenge:</u> The students participated in a discussion of professional ethics and how the practice of engineering is responsible to the general welfare. The students reviewed the professional engineering code of ethics and applied ethical concepts through a board game featuring the Dilbert characters. Students competed to be the most ethical in their behavior.

Field Trip to Flight Safety International: The students traveled to a local engineering company that manufactures flight simulators for customers worldwide. The tour emphasized the multi-disciplinary nature of engineering projects, the business side of engineering, and the responsibilities of engineers in the workplace.

Professional Presentations: Each of the two-person groups from the other activities was required to create a five-minute talk about one project or theme of the academy using PowerPoint. The students were given guidelines on good presentation practices and were allowed to proceed under the guidance of the instructors and high-school teachers. The students presented their talks at the closing banquet with their families and friends as an audience.

Results of the Academy

The Academy has four primary objectives, and evaluations were carried out during and after the Academy to determine whether or not these objectives were met. The objectives were:

Objective 1. Students Can Describe the Basic Principles of the Engineering Process
For this objective, the goal was to provide the student with sufficient information about what engineers do, the process of engineering design, and the relationship of the engineer to both the public and to the corporate world. To address this goal, the investigators endeavored to include design activities into as many of the main activities as possible, to address specific aspects of the design process in the activities, to expose students to practicing engineers, and include a specific activity addressing engineering ethics. Some of this information was included in the laboratory notebooks provided to each student, and some was built into the activity itself.

Objective 2: Describe specific types of electrical engineering problems and applications.
For this objective, the goal was to introduce the students to basic problems and concepts in electrical engineering and build upon them throughout the academy to a point where the students could understand the real-world applications. The laboratory activities were structured to build upon one another to develop more sophisticated electrical systems and tie those systems to real applications. The electrical circuits activity was the foundation for all of the electrical laboratories. The digital logic and electric car laboratories extended the concepts, and the optical communication laboratory was intended to integrate all of the prior experiences.

Objective 3: Learning About Teamwork Principles.
For this objective, the goal was to learn about the process of working with someone else, particularly on an engineering design project. The main efforts made in obtaining this objective were to employ team-building activities, have the students work on teams for a variety of different challenges, and faculty and teacher facilitation of cooperative efforts.

Objective 4: Complete projects and presentation for demonstration to peers and teachers.
There were two primary goals for attaining this objective. First, the students would have physical end products that could be shown to others outside the academy. The most successful of these was the programmable light sign, which each student received. Students were also allowed to take electrical components and circuitry home with them. Second, the student had to give a presentation at the closing event, which all of the students successfully completed.

To assess the project's effectiveness in meeting the first two objectives, a questionnaire was given at both the beginning and end of the academy. The questionnaire consisted of two parts. The first part made several statements about the practice of engineering and asked the student to rate the accuracy of the statement on a scale from one to four, with one representing a totally inaccurate statement, and four representing a statement that was entirely accurate. The second part asked a series of multiple-choice questions on the practice of engineering. The same questions were asked at both the beginning and the end of the academy, and the desired result was an increase in the number of students who marked the correct answer to each item. Some examples of the results are presented in Tables 1 and 2 below, showing the percent correct.

Question	Monday (% correct)	Friday (% correct)
Part One		
An engineer must know how to communicate effectively.	100	100
Good design practice is to build the entire system and then test	42	64
An engineer is ethically responsible to the general public first	32	95
An engineer builds new things out of existing things	47	68
A typical engineering design is limited by specifications and regulations	56	59
Part Two		
Which of the following is not part of an engineer's job?	58	64
In order to solve a typical engineering problem, you must…	47	73
Which of the following steps is not part of the design process?	44	61

Table 1: Sample questions and results related to Objective 1.

Question	Monday (% correct)	Friday (% correct)
Part One		
A complex circuit is a combination of simple circuits	68	73
A microprocessor is used to control complex systems	32	32
An operational amplifier decides which signal is bigger	63	86
Once a chip is programmed, the program can't be erased	32	41
Part Two		
The relationship between voltage, current and resistance is:	45	77
What tools are used to solve a digital logic problem?	27	73
Which is not a function of a receiver circuit?	9	14
What areas of electrical engineering apply to artificial vision?	68	82

Table 2: Sample questions and results related to Objective 2.

Evaluation of Objective 3 was performed primarily by observation and by conversations with the students during breaks. The team-building activity on Monday evoked the most comments from the students, all of which were highly positive. The students openly discussed their solutions for overcoming the communications challenges amongst the groups, and good strategies were adopted in later stages of the activity. Faculty observation of activities repeatedly found that the students were capable of sharing responsibilities and allowing partners to work through problems before moving on, with only a few exceptions.

In addition to evaluating the objectives, individual activities were evaluated, along with the overall program. In these evaluations, the students responded to a statement on a scale from 1 (strongly disagree) to 5 (strongly agree). Sample results from the overall evaluation are given below in Table 3.

Question	Average
The faculty and staff were able to answer questions in ways I understood.	4.727
The faculty and staff were respectful in their treatment of the students.	4.955
There was a good balance of lecture and project work.	4.682
The faculty lectures were clear and understandable.	4.500
The written material for the laboratories was clear and helpful.	4.217
There was plenty of lab material available to complete each project.	4.773
If I finished an activity early, there was additional material to work on.	3.909
I would recommend this academy to a friend or classmate.	4.636

Table 3: Overall evaluation results, showing the average response.

Individual Activity Evaluations

For each activity, the students were asked four questions.

1. Was the purpose of the activity clear, and was it relevant to engineering?
2. Was the material clear and well presented by the instructors?
3. Was the activity of an appropriate length and level of difficulty?
4. Would you include the activity in the next academy?

Some sample results are shown in Table 4. The average answer for the activity for each question is presented.

Question	Circuits	Electric Car	Digital Logic	Communications
1	4.435	4.909	4.762	4.571
2	4.130	4.500	4.238	4.381
3	3.782	4.455	4.571	4.476
4	4.130	4.818	4.810	4.524

Table 4: Average results for evaluation questions for selected activities.

Conclusions

Questionnaire Results

In both parts of the questionnaire, there were many questions where an increase in correct answers was observed, and some questions where no improvement was seen. It must be noted, however, that there were several questions that most (> 90%) of the students answered correctly on Monday, and so no improvement in these questions was expected. The greatest increases in the number of correct answers occurred on questions that were directly and repeatedly addressed during the course of the academy. The least improvement was observed on questions that, in reviewing the events of the week, were not as clearly addressed. Many of these topics were not addressed well because of changes in the schedule and planned activities or imperfect timing of some of the activities. It was noted by the teachers that some of the questions were too broad and allowed for misinterpretation by the students even if the topics were covered well. The most significant change for future academy sessions will be refining the questions to be more specific and ensure that the questions are basic enough that they will be covered in spite of planning or schedule changes during the Academy.

Overall Evaluation

While most of the evaluation results were very positive, the Academy staff identified two areas that needed improvement. The first area is the clarity and helpfulness of the written lab materials. Efforts were made to remove sections that did not directly apply to what the student was doing in the physical laboratory, particularly in the Circuits and Optical Communications materials. In all labs, schematics were added to give students guidance on connecting their circuits on the breadboards. The second area is the need for additional or advanced work for students who finish an activity early, for whatever reasons this might happen. This was particularly problematic in the Circuit laboratory. There were three or four students who had taken circuits material in a high-school course prior to the academy. These students contributed most of the lower scores, and this is reflected in the lower averages for this activity. The Academy staff suspects that the students were bored and/or held back by their partner who was new to the material. All of the activities have been rewritten with additional exploration options for such students to give them direction and focus after the original material is completed. In addition, pairing students with advanced knowledge and letting them work further ahead is proposed as a future solution.

Teacher Notes

At the end of the Academy, the teachers were asked to provide written and/or oral comments evaluating the Academy and suggesting changes for following years. Many of the comments reflected the evaluations and comments received from the students. The most important comment provided by the teachers was the need for a better teacher training session so that the teachers were better able to help the students and the staff during the activities. This was, in part, due to a problem with teacher recruitment, as many of the teachers were not added to the program until 2 weeks before it started, and this made scheduling difficult. However, a full day session is planned for future Academies to allow the teachers to work through some basic questions and problems during the week before the Academy.

Summary

The Electrical Engineering Summer Academy for Pre-College Students allowed students and teachers to participate in team-building, professional development, and technical activities designed to teach about the engineering profession and the field of electrical engineering. Activities included laboratories in electrical circuits, designing an electric car, soldering, a field trip, and discussion about ethics. Students worked in two and four-person teams, and made presentations on their experiences.

A formal evaluation of the entire academy revealed ratings of 4.5 or greater out of 5 on most aspects of the academy, though some areas indicated a need for improvement, such as clarity of written materials and the availability of additional material for advanced students who finished early. Changes were implemented for following academies, including the removal of extraneous materials, the inclusion of more wiring diagrams, and more concise laboratory instructions. Plans are in place for pairing up students of similar abilities to reduce friction within teams and allow advanced students more opportunity to explore beyond the basic material. Additional assessment examined whether the students acquired knowledge during the academy. Improvement in knowledge was demonstrated on over 50% of the survey questions. The students also demonstrated improvements in teamwork skills. In addition, a formal training session for teachers assisting with the program will be implemented to allow the teachers to be more effective in guiding the students through the material.

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