

TECHTRONICS: HANDS-ON EXPLORATION OF TECHNOLOGY IN EVERYDAY LIFE

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Abstract

Techtronics is an after school science enrichment program that encourages at-risk middle school students to pursue careers in engineering and technical fields. A joint venture between the Pratt School of Engineering at Duke University and Rogers-Herr Middle School in Durham, North Carolina, Techtronics seeks to stimulate intellectual curiosity in engineering through exposure to four engineering disciplines: civil, mechanical, electrical/computer, and biomedical engineering. The mature program now includes fully developed lesson plans for two sections of students, Techtronics I for 6th grade and Techtronics II for 7th grade, each led by a graduate student coordinator and five undergraduate teaching Fellows. Emphasis is placed on learning through hands-on experience and creating an environment that encourages inquiry. Students first study applicable scientific theory and are introduced to instrumentation and software tools that will be needed later. Each unit then culminates in the construction of a related project such as balsa wood bridges, Lego robotics, AM radios, or heart monitors. With a student return rate of over 70% for 2003-2004, the program is achieving its goal to provide a stimulating creative outlet for students with interest in science and engineering. Techtronics is funded by a three-year grant from the Burroughs Wellcome Fund Student Science Enrichment Program whose goals are to improve students' competence in science, to nurture their enthusiasm for science and engineering, and to stimulate interest in pursuing careers in engineering and the sciences. This paper gives a brief overview of the Techtronics program and discusses methods of motivating students in an after school setting

Introduction

The Techtronics after school program, funded by a three year grant from the Burroughs Wellcome Fund, places undergraduate and graduate engineering students in the classroom teaching engineering to students at Rogers-Herr Middle School in Durham, North Carolina. The program is an extension of the K-PhD program at Duke University's Pratt School of Engineering¹. Initiated in the fall of 2001, Techtronics utilizes college engineering students as instructors and mentors for middle school students in an after school program that teaches engineering through small group projects. Undergraduate and graduate engineering students have been used in middle school classrooms in engineering outreach classrooms at other institutions including the University of Colorado at Boulder², the University of Texas at El Paso³, and the New Jersey Institute of Technology⁴.

The primary goal of the Techtronics program is to empower students to realize the excitement and potential for innovation in engineering through a simplified introduction to technology as students are often intimidated by science and mathematics. The intention is that, after participating in this program, these students will be more interested in math and science in high school and ultimately more inclined to pursue engineering at the college level. These goals are accomplished through hands-on exploration of the four engineering disciplines offered at the Pratt School of Engineering: mechanical, electrical and computer, biomedical, and civil and environmental engineering. Curriculum development strives to enhance the learning experience by incorporating technology to which students would not ordinarily be exposed. In each unit, students develop teamwork skills through completing hands-on projects in groups or pairs. Students are encouraged to “think outside of the box” and be creative in their approaches to solving design challenges. This process of inquiry through creative design is most effective when the students have the opportunity to perform meaningful tests of their designs in order to gain understanding from their successes and failures. Some of the units rely more heavily on technology to arouse student curiosity while others rely more heavily on inquiry. Increasing the participation of underrepresented groups in engineering is another important goal of the program. Specifically, the Rogers-Herr Middle School student body is 97% African American. Additionally, participants in Techtronics are selected to maintain an even ratio of girls to boys in each section.

This paper contains advice for universities interested in starting and developing similar after-school programs at local K-12 schools. Specifically, it provides recommendations for program structure, advice on the importance of support from partner schools, and information on implementation costs. Methods for maintaining students’ interest in the material throughout the year are also discussed.

Structure

Techtronics is currently designed as a two-year program for sixth and seventh grade students. Each section of Techtronics meets once per week for 2 hours after school. The classes are led by six Techtronics Fellows from Duke University’s Pratt School of Engineering. Each section is composed of approximately twenty students, five undergraduate teaching Fellows and one graduate student coordinator. The graduate student coordinator is also responsible for communicating with parents and with middle school faculty. The most common classroom structure involves splitting the class into small groups of four to five students, each facilitated by an undergraduate teaching Fellow. The high Fellow-to-student ratio ensures that students are getting individual attention and encouragement while the graduate student coordinator is free to move among the groups to maintain a positive working environment and keep the teams on task.

There are four units taught each year with those taught in Techtronics II reinforcing and extending concepts learned in Techtronics I. Units are approximately five weeks in length. Typically, the first 1-2 weeks are an introduction to concepts that are used to complete a hands-on project during the last 3-4 weeks.

At the end of the unit, students are invited to the Duke campus for a half-day Saturday field trip. At Duke, students learn about current research relating to the completed unit, show their parents

completed projects, and get a glimpse of what life in college can be like. For example, for the Mars Rover Design Challenge, students are given a demonstration of a lab researching interactive robotic arms. For the solar racecar project, students may see a demonstration of the Duke Motorsports racecar. Both Techtronics sections generally have the opportunity to see what the other section is doing, thereby reinforcing a sense of community in Techtronics. Parental involvement is an important part of Techtronics. Each of the Saturday sessions gives the parents a chance to interact with the teaching Fellows and to see first hand what their children are working on.

Middle School Leadership

It has been the experience of the Techtronics Fellows that a program such as this requires strong leadership, not just from the university, but from the middle school involved. The support of the administration at Rogers-Herr Middle School, especially the Principal, Ron Roukema, has been outstanding and has been crucial to the success of the program. Additionally, the strong involvement of one of the science teachers at the school to serve as a liaison for the program is very important. Over the past two years, Anndrea Carey, a seventh grade science teacher, has filled that role by collecting signup forms and allowing the use of her classroom for the program. The relationships that Techtronics has developed with Rogers-Herr Middle School have been important both in terms of getting things done as well as in avoiding potential conflicts when trouble arises. For instance, there have been occasions where Techtronics students have not fully cleaned up at the end of the session. Teachers at the school are rightfully annoyed by this, but by ensuring open lines of communication between the teachers and Techtronics, specifically the graduate student coordinators, these situations have been rectified quickly.

Relationships with middle school faculty are also crucial in order to provide legitimacy for the program in the eyes of parents. Parents will ask teachers and administrators about programs such as Techtronics in order to decide what is best for their children. For those reasons, Techtronics has always been as open as possible with teachers at the school. Parents may not always be able to contact the Fellows at Duke, but they are always able to ask school administrators about the program. For that reason, it has been very important to keep the liaison, Anndrea Carey, and the school's secretary up-to-date on Techtronics activities.

Program Costs

The largest cost of the Techtronics program is paying the Techtronics Fellows. Each undergraduate Fellow receives \$3,000 per year, while each graduate student coordinator receives \$8,000 per year. Although there are only 2-3 hours a week of teaching in class, these stipends include an expected commitment of 10 hours/week. This time includes regular training classes and meetings, but most importantly it covers preparation time. The program PI, Dr. Gary Ybarra, together with the Fellows, design the curriculum and projects, which tend to take a lot of time due to the nature of the projects. It is important for the Fellows to practice building the projects in advance, so that they are familiar with the materials and methods they will be teaching in class. Often, a project that seems straightforward will be proven otherwise when actually attempted. In such cases, the project may be modified prior to trying it in the classroom, but only if it has been practiced by the Fellows ahead of time. The total cost of the Fellows for both Techtronics

sections is \$46,000 per year. Clearly, this cost could be reduced if the Fellows were paid less or there were fewer Fellows in the classroom. If the Fellows were paid less, though, they might not do as much work and the preparation time would be affected. If there were fewer Fellows in the classroom, the number of students per Fellow would increase, which would make it harder to work in small groups. This would affect the types of projects that could be attempted. For instance, with this age group, it would be difficult to do a project that required soldering without providing close supervision by the teaching Fellows.

Materials and supplies are another important cost of the program, but one that can be varied for different budgets. The cost of projects need not be prohibitive. Many exciting science projects may be built on a budget for low-cost projects such as solar ovens and balsa wood bridges. If a more substantial budget is available, undergraduate engineering students have the ability to take advantage of technology for teaching in unique ways that are not necessarily available to the middle school science teacher. By using the resources of Duke University, Techtronics Fellows have built circuits for demonstrations, obtained and tested educational fuel cells, and have built a display case for the components of a stand-alone solar photovoltaic power system. These are expensive projects that bring technologies to the classroom that schools would not ordinarily be able to afford or have the time to fully utilize. The materials and supplies budget needs to be highest in the initial year or two of the project in order to obtain tools. The supplies budget for Techtronics is \$9000 per year.

A final small, but important, budgetary item for this type of a program is a budget for snacks for the students. Snacks are consistently one of the most important parts of the program to middle school students. Also, it is hard for middle school students to continue concentrating on work at school if they have not eaten anything recently. Techtronics generally provides a snack and drink for each student at the beginning of Techtronics, just after school is dismissed. In order to maintain a clean classroom, the students must finish their snacks and throw away the wrappers before beginning their projects. The money for snacks comes out of the supplies budget and is around \$300 per year for two classes of twenty students each.

Motivating Students

The principal problem the Techtronics program faces is that, as an after school program, students are not motivated by grades, and therefore must be motivated by a genuine desire to learn the material. The program is voluntary, but some students are signed up by their parents and are not always interested in being there. Even for the students who are interested in being there, some of the projects are more exciting than others depending on their unique interests. Even for a project that excites student curiosity, without proper incentive, students might not do their best work because it is not important how good a job they do on the project. Exciting curiosity in students is the job of all teachers and this is especially true of the Techtronics Fellows.

The ideal approach is to create projects so exciting that all students will want to build them, so great care is taken to ensure that the projects themselves are as interesting as possible. The main motivational methods used in Techtronics are to use technology and creative design to generate student interest in projects. Each two-year unit pair exposes students to technology they would not normally have access to in the classroom. Additionally, each unit creates an atmosphere of

inquiry by allowing students to creatively design something and then test their designs. Some units are more effective at creating inquiry than others and some units utilize more exciting technology than others. Often, this is a tradeoff between technology and creativity. The more technologically advanced a particular project is, the more help the students require to complete it and the less creativity they are able to use during the design process. One of the hardest parts of designing the Techtronics curriculum has been to come up with ways to encourage creativity in design while still ensuring that the students complete projects that they are proud of. Two of the two-year pairs of units in Techtronics will be examined below to illustrate this point and examine the effectiveness of motivating students with technology versus creative design.

Motivating students through educational material is ideal, but it is not generally enough for the entire class as described previously. Techtronics has employed a number of other methods to motivate the students including competitions, prizes, and group selection. Design competitions have proven effective in motivating students more than simply building a project. Competition is good because it forces students to attempt different solutions to a problem and gives them a scale with which to measure the effectiveness of their solutions. It also forces students to complete projects more thoroughly and pay attention to the details that really make them work. There are drawbacks to competition as well. Most importantly, it implies that the projects that do not win were not good. It is especially important to emphasize that all ideas are good and that the class can learn from each of them.

Linked to motivating students with competition is the concept of using prizes. These can be small prizes, such as treats or small science items, or larger prizes such as gift certificates or T-shirts. The danger with giving prizes is that the students will then expect them. Small treats given out each class period for coming up with good questions has been effective. On the other hand, prizes for the end-of-unit competitions must either be comparable throughout the year, not used at all, or used increasingly as the year goes on in order to maintain the appropriate level of student expectation. If there is a prize for the first unit's competition, but not the second, the second competition will not have the same importance in the mind of the students as the first.

The groups students are placed in are crucial to their desire to complete the projects. Some students work better with their friends, some students work better without their friends, and certain students will not work with certain other students. For these reasons, group selection must be approached carefully. Sometimes students are allowed to pick their own groups and sometimes they are not. Despite the fact that the same students would like to work together all of the time, it is important for students to learn that this is not always possible. If a student is placed in a group in which they do not want to work, motivating that student becomes much more difficult. On the other hand, students working with their friends sometimes work very well together. Understanding the particular class is crucial to motivating them to complete their work.

Projects

Each two-year pair of units used in Techtronics I and II uses technology and inquiry-based learning through creative design in order to accomplish its learning objectives. Most of the projects in Techtronics I and II have been described previously^{5,6}. All of these units are now more thoroughly integrated into two-year pairs of units. Two will be examined below to discuss

how each motivates students to engage in the material. Specifically, the Lego Robotics and Circuits units are examined with respect to their use of technology, inquiry through creative design, and competition as motivation for students.

Lego Robotics

Lego robotics is taught in both Techtronics I and II in order to introduce students to concepts in mechanical engineering, computer science, and electrical engineering. The materials available for these units are some of the best for allowing students to creatively design high technology. The Lego Dacta Mindstorms kits and the Robolab software make it possible for students to create and build their own robots. Students are excited by this technology right away and begin exploring it. To facilitate this, students in Techtronics I are simply told to build a robot and program it to do something. Each group builds some kind of a robot and then programs it. The open-ended project allows each group to explore those aspects of the technology that most interest them. Some groups concentrate more on the mechanical engineering and building side of the unit. For instance, one group built a front-end loader and programmed it to move and lift objects. Other groups spend more time on the computer programming and electrical engineering aspects of the unit and make use of the touch sensors. One group designed a car that would back up and turn a different direction depending on whether an object hit the left or the right side of the car. This requires a much more complex computer program. The Techtronics Fellows challenge each group to stretch its designs according to the individual interests and capabilities of the students. At the end, the students present their projects to the class. This is important, not only because it allows students to work on their presentation skills, but also because it allows students to see a variety of possible creations from the Legos. In order for the inquiry process to be effective, it is important for the students to discuss what they have learned.

In Techtronics II, students work in groups of four facilitated by one of the Techtronics Fellows. The project was adapted from some of the projects done in the FIRST Lego League⁷. Groups are presented with the challenge of designing and constructing a vehicle out of Legos to navigate the “terrain” of Mars. The rovers are required to navigate an obstacle course built to simulate the surface of Mars and climb a ramp that represents the largest volcano in the solar system, Olympus Mons. Techtronics II builds on the open-ended project of Techtronics I by providing a challenge designed to intimidate the students at first. Through frustration and eventual success, the students discover the power of engineering design. The project promotes inquiry-based learning through creativity as the students discuss the advantages and disadvantages of various designs, but the designs must be constrained to help the students finish in the allotted time period. In the end, it is important for the students to discuss which designs were most effective and why in order to learn from the project. Additionally, the Mars Rover project employs an aspect of competition as the students compete for an imaginary NASA grant for their designs. Competitions such as this are most effective when the guidelines are clear and unchanging from beginning to end.

Circuits

Circuits are introduced in both Techtronics I and II in order to introduce students to concepts in electrical engineering, and in the case of Techtronics I how those concepts may be applied to

biomedical engineering. Teaching students circuits is exciting for them because it explains things that they have probably never been exposed to such as how circuit boards are constructed and how the tiny electronic components on them function. On the other hand, electrical circuitry is relatively complex and therefore it is difficult to develop creative projects for the students in which they can build something through trial and error experimentation. Instead, the students must follow specific directions to build projects. In Techtronics I, the students learn about electrical engineering basics such as Ohm's law. Then, they assemble a heart monitor circuit kit in groups of four. The concept of a heart monitor is exciting because the students are given the opportunity to measure their own heart rates. In this portion of the project, inquiry is encouraged as the students measure their heart rates while they do different activities. Unfortunately, other than that, there is not much room for creativity or inquiry as the students follow directions and build the kits. The kits require soldering so supervision is crucial. On the other hand, the students love soldering as the concept of melting metal is instantly fascinating to them. This, and the concept of building their own circuit boards, help hold the interest of the students through the project.

Techtronics II builds on the electrical engineering understanding from Techtronics I to build AM radios. Their knowledge of electric circuits is extended to include magnetism as the concept of electromagnetic radio waves is introduced. Once again, the main project of the unit does not rely on inquiry-based learning methods because the circuit is too complex. The fascination and motivation for learning is driven by the excitement of using technology that is above that which is normally available to students of this age group. This has proven effective in Techtronics also because students are motivated to build the radios and heart monitors correctly so that they work.

Assessments

A number of methods are used to assess Techtronics' ability to meet program goals, including looking at year-to-year retention rates and student surveys. First, the student retention rate was approximately 70 percent between Techtronics I and Techtronics II during the 2002-2003 and 2003-2004 academic years. This was an improvement over the previous year and has allowed the program to truly become a two-year program in which the second year builds from knowledge developed in the initial year as originally intended.

Second, students complete evaluations at the end of each unit. Long-term studies are required to determine the lasting impact of the program. Data is provided for the end-year-surveys from the 2002-2003 academic year compiled from both Techtronics I and Techtronics II.

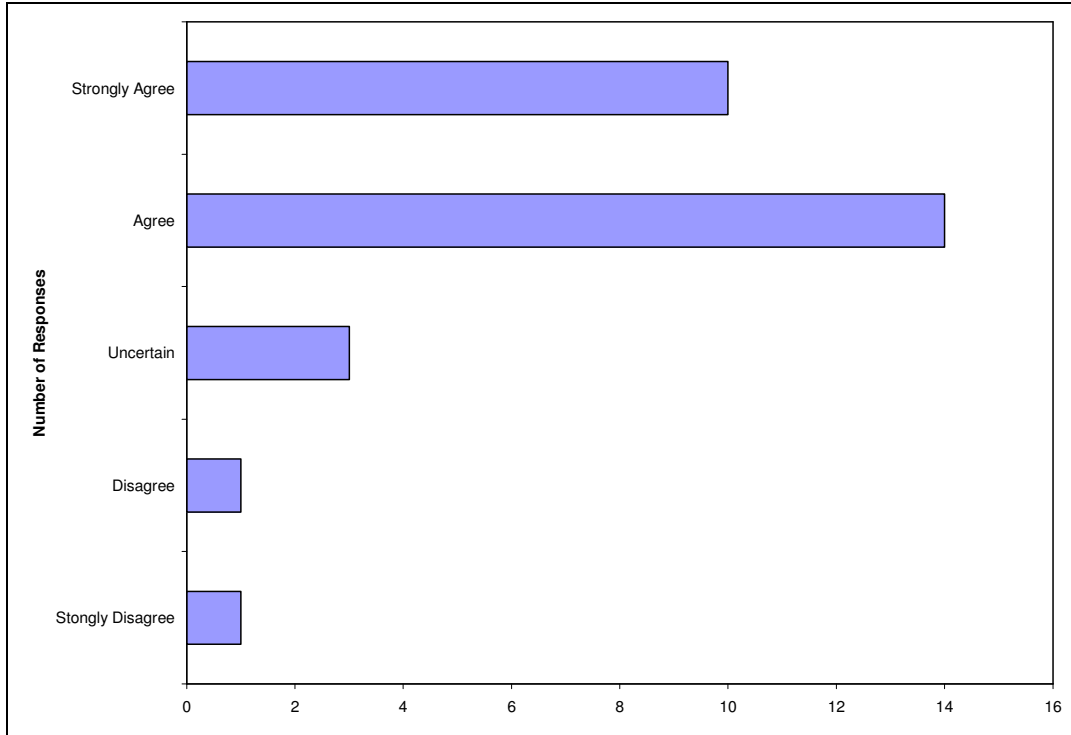


Figure 1. Student responses to the statement, “This program helped me understand science better.” Survey taken at the end of Techtronics in 2002-2003. These include results both from Techtronics I and Techtronics II.

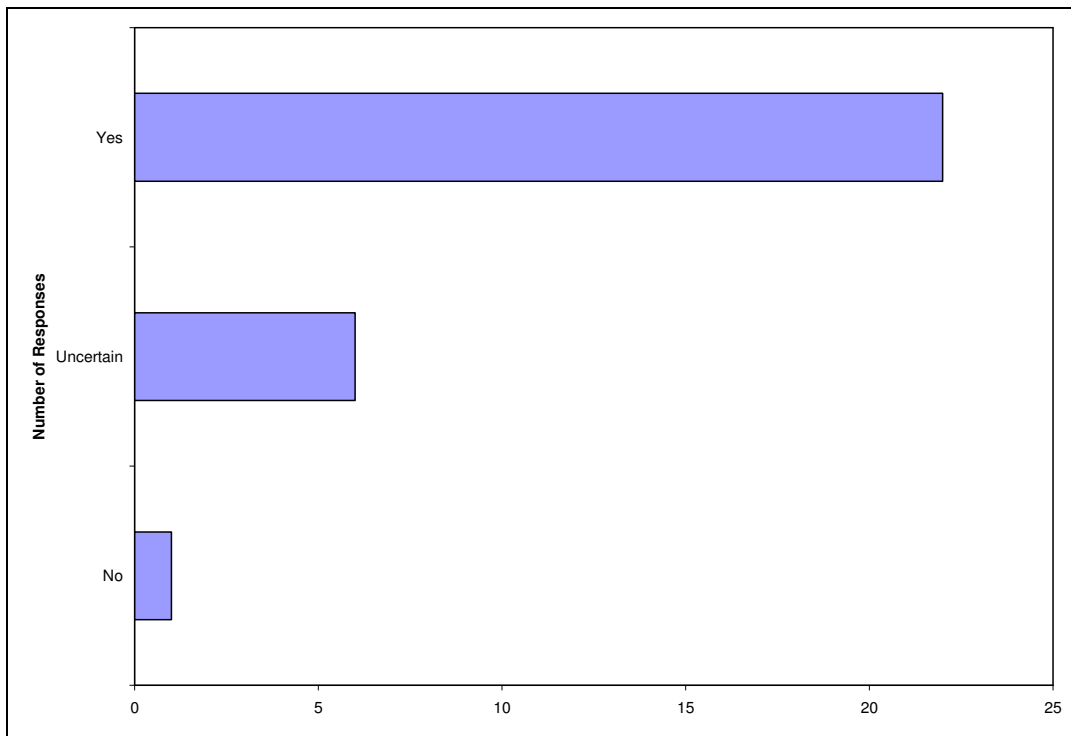


Figure 2. Student responses to the question, “Would you participate in another program like this?” Survey taken at the end of Techtronics in 2002-2003. These include results both from Techtronics I and Techtronics II.

Conclusions

This paper has provided information on how Techtronics: Hands-on Exploration in Everyday Life motivates middle school students to learn in an after-school setting. Techtronics partners Duke University Pratt School of Engineering graduate and undergraduate students with Rogers-Herr Middle School students in an after-school program designed to inspire curiosity in engineering and the sciences. Survey data from students based on the complete second year of Techtronics, 2002-2003 academic year have been positive. Long term studies will be required to determine if the program has increased student participation in science, math, and engineering later in life.

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