Robotics in Education:

ROBOLAB and robotic technology

As tools for learning science and engineering

An honors thesis for the Eliot-Pearson

Department of Child Development

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Tufts University, 2003

Abstract

This thesis evaluates an eleven-week after school workshop for third through sixth grade children, which uses robotic software with LEGOs in order to help the children learn about the principals of science and engineering. The evaluation is based on pre- and post-questionnaires, observations by various people, and the projects and explanations that the workshop participants produce. It examines the efficacy of technology in fostering deeper understandings of science and engineering principles, based on the children's experience with the LEGO Mindstorms construction kit and ROBOLAB, the accompanying programming software. The workshop was formed in order to assess how robotic principles that are being used at a college undergraduate level can be integrated into an elementary curriculum.

Acknowledgments

I would like to thank a number of people who helped me to accomplish this work. My advisor, Dr. Marina Bers, has given me invaluable feedback and support throughout the yearlong process of organizing my thoughts, making a plan, and putting it in writing. She has given me a perfect balance of independence and helpful guidance. Diana DeLuca, my partner throughout this endeavor, spent countless hours doing her work, my work, and our work in order that we were both prepared for our next activity, whichever that may have been. Dr. Caroline Cao and Dr. Steve Morrison have made generous contributions to the work, by way of general ideas, specific writing hints, and making the big picture visible. The members of the Robotics Academy have been tremendous in their knowledge, motivation, and enthusiasm for the project. In addition, I extend my thanks to my friends with the hopes that they will forgive me for neglecting them on so many nights of “thesis meetings.” Finally, I am grateful for the most supportive family that I could ever imagine. Thank you all.

Table of Contents

Introduction/Purpose

This section will introduce the thesis by describing Seymour Papert's theoretical framework of contructionism, the notion of powerful ideas, and computer-based after school settings. These three areas will be compared with a more traditional learning environment.

General technology in education

When we think of a traditional learning environment, we picture a teacher who dictates everything she knows to a group of students that records the information, which is eventually recalled and committed to memory for a short amount of time until after the test. We picture students sitting quietly, scribbling away as a teacher talks on and on, occasionally making a chalking on the board in front of the students. Even when students are asked to apply the information to a so-called real life situation, they use the information in a systematic way to solve an arbitrary problem that probably has no significance to them. When the bell has rung and the class is over, the students tuck the new information into bags and backpacks, despite whether or not it has ever passed through their brains. After several weeks or months, the standardized test day arrives, and the students demonstrate how well they are able to recall the information that the teacher has presented to them. However, what have they actually learned? Do they even care about the information or want to understand it?

Many traditional learning environments have stringent requirements as to subject matter that is to be covered and the method by which to cover it. In every state across the country, there exists the Curriculum Frameworks, which detail the expectations of topics to be covered by each state. Massachusetts is no exception, as its students are expected to proceed through a series of topics and skills, and at the end, they presumably know everything that they have covered in class (Massachusetts Curriculum Frameworks). Many school districts evaluate a school's effectiveness based on how students perform on standardized tests. In Massachusetts, students are evaluated at particular grade levels by standardized tests called the Massachusetts Comprehensive Assessment System, or the MCAS. Thus, students learn how to answer problems that are likely to appear on these tests. This doesn't leave much time for integrating other modes by which children learn into a classroom, whether it is for the purpose of learning the prescribed material or other material. For instance, technological tools, which are becoming more and more prevalent in our society, are not used to a great extent in schools. Many classrooms house one or several computers, but they are most frequently used as tools to help students practice, in a drill format, that which they're learning in the classroom curriculum. They are not there to allow for discovery in students' areas of interest.

This forces students to pursue other academic interests outside of school, where they have more flexibility in terms of what and how they learn. Students can participate in workshops, visit museums, and join community-based educational programs that offer environments conducive to the thorough exploration of these areas while appealing to the students' interests. These environments also may offer technological tools that aid their exploration when schools are not able to offer such tools or willing to use them for these purposes. **This thesis will examine the effectiveness of an after school robotics workshop in promoting a deeper understanding of science and engineering, while allowing for its participants to make concrete constructions based on personal interest.**

Papert, constructionism, and powerful ideas

Now imagine a learning environment in which young students are busy working on projects that all look very different. A teacher is present in order to give the students helpful prompts when they find themselves stuck. The children are engaged in projects about topics of personal interest, and they must represent some aspect of their topics with physical objects that they have constructed. The learning style in this scene is based on the theoretical framework of constructionism, presented by Seymour Papert (Papert, 1993).

Papert's theoretical framework of constructionism is based on Piaget's theory of intellectual development that uses the term constructivism to describe how children take knowledge from the outside world and organize it within their minds so that they understand it. Papert described the process of building knowledge in a more concrete way. His term constructionism asserts that the actual concrete design and construction of a project is the basis upon which students learn, and technology can provide opportunities for this design and construction.

The engineering design process is a way that the principles of constructionism are put to practice in an academic setting. This process gets children thinking about a problem or situation that is meaningful to them and that they'd like to address with their projects. Then, they must invent a way to solve the problem or manage the situation. One key element is that children are working out their own questions and answers (Duckworth, 1972). Next, they go about designing and constructing. During these processes, children manipulate objects and play around with ideas, all the while arriving at their own powerful ideas about the topic and about the tools with which they're working. A child's powerful idea is his own way of understanding something about the objects with which he is working that he didn't previously understand. It is a powerful idea because he has discovered it himself and because the idea is important within a particular domain. It is probably an idea that an adult could easily explain to him, but it is powerful because he has uncovered it for himself, and it has relevance in a larger context, which makes the idea and understanding clearer and more meaningful (Bers et al., 2002).

Eleanor Duckworth describes the process of developing one's own questions, answers, and the powerful ideas involved as making new connections between things that the child is already very familiar with (1972). She refers to powerful ideas as wonderful ideas, ideas that the child has just discovered on his own, whether they are mainstream ideas or not. Consequently, students engaged in this process are motivated. They are motivated to explore a topic that is particularly interesting to them, using the powerful or wonderful ideas that they have discovered and that make sense to them. They are motivated to construct something that has relevance to their topic, and they are motivated to discover the tools that will aid them in the construction process. Resnick, Berg, and Eisenberg describe children's personal interest in a project as a strong connection that is established as a result of feeling responsible for all aspects of the project (2000). The connection and personal interest serve to motivate. Papert would add that children are motivated by the control they have when they use technological tools such as computers, that allow them to make all the decisions about their projects through programming (1980). They are motivated to learn other things in the process. If they need to learn an engineering concept to use the technology or to achieve their project goals, they will because the overarching vision is so interesting and meaningful to them.

In addition to the design process as an integral part of the constructionist approach, self-reflection is the step that connects the whole process and brings meaning to the other parts. It gives children an opportunity to think about and assess their own thinking process and their role in the creation of the project (Bers et al., 2002). This may also lead to a deeper understanding of the topic and the steps and tools involved in creating the project related to the topic. There are many avenues that promote self-reflection. Several forms of documentation may be used as modes of self-reflection, such as design journals, videotape recordings, and exhibitions in which children can share their projects within a certain community. The sharing of projects within a community lends itself to self-reflection because as children explain and answer questions about their projects, they better understand their own processes and the elements involved (Bers et al., 2002).

The learning that occurs during the construction process may seem trivial, but it is at least as important as the learning of the actual topic. This is partly because the learning is based on the child's own powerful ideas and subsequent interest in those ideas and the tasks surrounding them. Also, the abilities that they develop in the construction of the project are abilities that they will apply to the exploration of other topics of interest in future projects. Thus, when building their own creations they acquire skills that will enable them to build other creations and learn more about other areas (Papert, 1993). The best things children can have in a world that is so expansive are the opportunities to become familiar with something interesting through their knowledge and exploration.

This gives them more knowledge and more ideas with which to explore and get to know other things in the world (Duckworth, 1972).

The theoretical framework of constructionism is based on the fact that people learn complicated things without ever being taught. They learn things such as how to play complex videogames, how to do math in order to follow a recipe, or how to reason with parents in order to get what they want, and they learn these things because they are interesting and meaningful. Children can similarly learn science and engineering principles through the construction of meaningful projects. In applying constructionism to a learning environment, teachers play a different role in the children's learning process than they do in a traditional classroom. They are there to facilitate and guide, as opposed to dictate and direct. Papert, in his theoretical framework, uses the term instructionism to refer to the latter teaching style.

Those who believe in instructionism strive to improve teaching as a way of helping children to learn more. The focus is on the teacher. On the other hand, a belief in constructionism places the focus on changing the expectation that children learn best when following a rigid structure prescribed by educators. An educator using constructionist principles would facilitate a child's natural learning process by helping her to thoroughly examine something she's excited about. The educator would encourage the child to think in new and unique ways, without attempting to control what and how she learns (Resnick, Bruckman, & Martin, 1996). The educator must be accepting of the wonderful ideas that may seem irrelevant or trivial, and he must provide settings that suggest diverse ideas to the children so that they are free to explore what is meaningful to them. Children who are given the chance and encouraged to delve deep into the examination of their own ideas tend to have more ideas and work on their ideas to a greater extent than children who are educated with a more traditional approach (Duckworth, 1972). It is important to keep in mind that many technological tools engage children in construction, which can lead to the having of wonderful ideas. A child who engages in construction through these technological tools has many opportunities for wonderful ideas and is mortivated to discover them. Therefore, technological tools often lend themselves to the creation of environments that promote the having of wonderful ideas.

Technological instruments that enable construction, such as computers, particular software, and robotic technologies must be utilized for the purpose of giving children different contexts in which they can experiment with complex ideas. All too often these tools are used to drill students and present them with pre-programmed activities that will help them practice the things that they are learning in their classrooms. They are there to be assistants to the teachers (Papert, 1980). However, using the tools in these ways do not engage children in the construction that is so central to their developing deeper understandings about the concepts involved. In order to use the tools for construction, the children must have interactions with the tools, and a sort of relationship develops. When they can talk to the tools, such as programming a computer, they are teaching the computer how to think. As they do this, they are also thinking about how they themselves think, a powerful ability and a useful skill for future thinking (Papert, 1980).

There are obstacles to using these tools in academic settings. Technological tools are expensive and are often not considered to be helpful enough in the learning process to merit large amounts of school budgets. Currently, so much of what children do at school has an either correct or incorrect outcome, which makes for easy labeling of students as smart, dumb, artistic, and many other things, while making the students aware of their own capabilities and inabilities. The students come to define themselves based on these capabilities and inabilities, which makes it difficult to break away from them and prove differently. Technological tools that support construction and unique creations may give students chances to succeed in many realms, ridding them of labels (Papert, 1980). In order for this to occur, we must make it a priority to give schools and children these technological tools, and we must be sure that they're allowing children to explore complex concepts in order to develop their own understanding of them. Again, students can look to settings other than schools in order to have access to the tools that allow them to learn while they explore their interests.

Learning in a computer-based after school setting

Computer-based after school settings that utilize constructionist principles give children opportunities to work on projects in which they have a vested interest, while using technology that may not be available to them at school. In these settings, they have much more freedom with what and how they work. The instructors at these settings are not pressured to pull the children through a set curriculum or to make sure that they have the skills necessary to pass a test about the information. For these reasons, children are free to practice their own learning techniques, pacing and defining their own thinking processes. They operate according to the principles of the theory of constructionism. They use the design process to produce something relevant to them and to the after school environment.

For example, Computer Clubhouse, which was founded in 1993 as a result of collaboration between The Computer Museum and MIT Media Lab, is an after school learning environment for under-served communities. At the clubhouse, youth are supported through their design experiences and encouraged to engage in projects based on their own interests while using the computer technology that the environment offers (Computer Clubhouse). As another example, Tufts University's Center for Engineering Education Outreach holds a LEGO camp, in which students are encouraged, through constructionist principles, to work on projects that are structured to support the having of powerful ideas about science and engineering concepts, while they are afforded much freedom in how they complete the projects (LEGO Camp). When children are presented with the occasions in which they are allowed and encouraged to engage themselves with the technology and their own ideas, they change their attitudes about technology and the things that technology helps them to learn, and they develop a deeper understanding of the concepts involved. After school settings can provide these occasions.

Background/Context

This section will describe the path by which the project was structured. It will define the project at the undergraduate level and will introduce the means by which the child development undergraduates explored their own areas of interest, through a course for pre-service teachers and an after school robotics workshop for elementary students.

NSF and the Robotics Academy

The National Science Foundation granted a group of faculty at Tufts University with funding in order to initiate a movement that would improve undergraduate education.

They believe that by joining undergraduates from multiple disciplines to work on a team with a common goal that has real world application, the students will experience more meaningful education, which may be more effectively applied to postgraduate settings. They intend for the students to leave the experience with a greater appreciation for the application of their discipline, better preparation for the workforce and further educational experiences in which they'll be collaborating with colleagues from a variety of backgrounds, and with more of an understanding of the real problem that they addressed, as well as the project-based strategy that they used in addressing the problem (Rogers, Bers, Cao, & Morrison, 2002).

In order to include these goals into undergraduate education, the grant proposes the formation of the Robotics Academy. The purpose of the Robotics Academy is to unite a multidisciplinary team of undergraduates and involve them collectively in the teaching and discovery of engineering. The Robotics Academy at Tufts University is led by a group of faculty, including professors James O'Leary, Douglas Matson, and Chris Rogers of the Department of Mechanical Engineering; Steve Morrison of the Department of Electrical Engineering/Computer Science; Caroline Cao of the Department of Engineering Psychology, who also serves as leader of the Medical Robotics program within the Robotics Academy; and Marina Bers of the Department of Child Development.

Under the supervision of the faculty members, the participating students[1] work toward a common goal, the design and implementation of a robot that navigates narrow pathways. The goal is relevant in its response to current research about how to improve measures of the colonoscopy procedure. Each discipline represented in the group is

[1] The undergraduates in the group are AJ Schrauth, Matt Dombach, Jason Adrian, Eric Basford, Dave Cades, Dan Parent, Adam Wilson, Diana DeLuca, and Laura Hacker.

responsible for an aspect of the process of designing and implementing the robot. The mechanical engineering students are responsible for the design and construction of the robot. The electrical and computer science engineers are involved in the wiring of the robot. The engineering psychology students are responsible for making the robot user-friendly. The child development students are responsible for integrating the principles involved in the robot and its creation process into an educational curriculum. This thesis is concerned with the educational applications of such technology. Therefore, it will focus on the role of the child development students in devising a way to incorporate the concepts that govern the robot into a curriculum for children. Further information about the Robotics Academy can be found at http://www.tuftl.tufts.edu/Users2/EngEdu/robotics_academy/.

The child development students involved in the Robotics Academy have two major areas of interest. One area is the examination of the role of the teacher in using robotic technology in a classroom. The second is looking at how children learn with robotic technology, in particular concepts of science and engineering such as the lever, inclined plane, wheel and axel, screw, energy transformation, friction, four bar linkage, programming, robotic autonomy vs. remotely operated, structural analysis, and tension. In order to address educational technology from both a teaching perspective and a learning perspective, the child development students looked at pre-service teachers, or students working toward their teaching degrees, through an undergraduate course about robotics in education, and they evaluated an after school robotics workshop for elementary students.

Involving pre-service teachers

In addressing technology, and more specifically robotics, in education, teachers serve a key purpose. Teachers have much of the control over what and how they teach. For a variety of reasons, teachers tend to shy away from the use of technology in their classrooms. Perhaps they are not experienced themselves with the use of technology, making it a very difficult thing to teach and to use in teaching. Maybe they are not aware that technology in a classroom can bring a multitude of educational benefits. In either case, by exposing teachers to technology and methods of using it before they are in schools and operating in their own classrooms, it will make them more comfortable and able to use these tools for educational purposes. Therefore, an undergraduate course for pre-service teachers has been set up, that requires them to be skillful in the use of a robotic technology and programming language, LEGO Mindstorms and ROBOLAB and to have a thorough understanding of the theories behind using technology to teach children. The course is evaluated based on how the pre-service teachers learn the technology and anticipate using it to teach. It is team-taught by the Education and Technology Program Manager at the Center for Engineering Education Outreach at Tufts University, Merredith Portsmore and the child development students in the Robotics Academy, Diana DeLuca and Laura Hacker. It is supervised by professor of child development, Marina Bers. This course is examined to a greater extent in the thesis by Diana DeLuca about teaching with robotic technology (DeLuca, 2003).

The after school robotics workshop

An essential step in integrating technology into education is the examination of the most effective ways to do so, in terms of how it maximizes children's learning. How can technology promote a deeper understanding of subject matter? The child development students in the Robotics Academy seek to know more about how children learn with robotic technology and the advantages and disadvantages such technology brings to the learning process. They address these questions based on observations of an after school setting that uses robotic technology combined with teaching techniques based on constructionist principles. After school programs allow much more freedom in their design and implementation because they don't have to follow a prescribed curriculum, as do schools. So, the workshop includes any type of activity that may be helpful in answering questions about learning with technology. In addition, documentation is a valuable aspect of the learning that occurs based on the constructionist philosophy, and it assists in evaluating the efficacy of the program. For these reasons, video recording and photography are used to document the workshop. In schools, there are many more implications for using documentation in these ways, as opposed to the after school setting, where we are much freer to do so. Therefore, we developed an after school robotics workshop in order to address these questions about learning with robotic technology.

The workshop is composed of eight third through sixth grade boys, who use LEGO Mindstorms and ROBOLAB, robotic construction kits and programming technology, to carry out various challenges. The challenges and activities explore basic principles of science and engineering, including the lever, inclined plane, wheel and axel, screw, energy transformation, friction, four bar linkage, programming, robotic autonomy vs. remotely operated, structural analysis, and tension. Once they achieve proficiency at using the ROBOLAB tools, they begin creating their own robotic inventions. Finally, during the last few weeks, the boys attempt to solve a similar problem to that of the Robotics Academy students by designing and building tube-crawlers, robots that can navigate pathways, but with slightly different ramifications. During these sessions, the LEGO counterpart of the Robotics Academy tube-crawler is introduced, which is more functional and relevant to what the boys are doing than the actual robot.

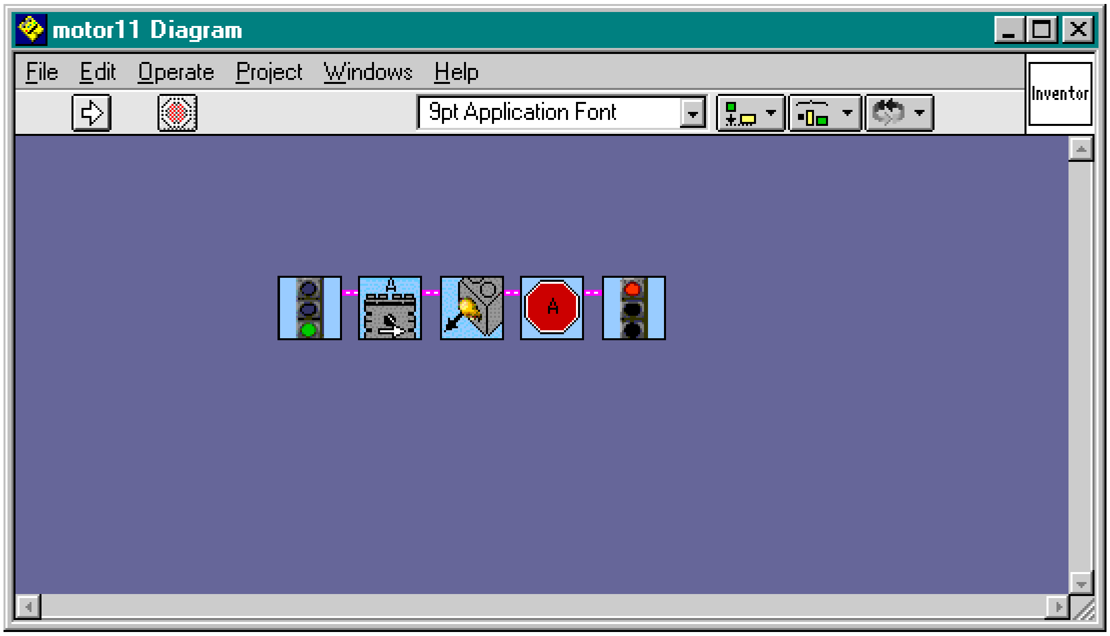
LEGO Mindstorms and ROBOLAB

LEGO Mindstorms is a robotic construction kit developed by LEGO and MIT Media Lab. The kit contains an RCX programmable LEGO brick (see figure 1) and hundreds of LEGO pieces, sensors, and motors. The RCX brick can be programmed to power motors, activate light bulbs, and accept input from sensors. The program messages are transferred to the brick via infrared, a way of transmitting energy, from a tower that connects to the computer running the programming software, to a panel on one side of the brick (Bers et al., 2002). The miniature computer inside the LEGO brick is able to then perform many functions through its input and output ports.

Figure 1 *RCX, programmable LEGO brick (taken from www.hobbytron.net/legomindstorms200.html)*

ROBOLAB is the software tool that accompanies the LEGO Mindstorms construction kits and was developed by the partnership between Tufts' Center for Engineering Education Outreach, LEGO Education, and National Instruments (ROBOLAB). It is software with a user interface based on symbols that represent various pieces of the LEGO Mindstorms hardware (see figure 2). Therefore, it makes programming much more visual. The software consists of multiple levels; each one offers slightly more or less options than the one before or after it. Due to the wide span of the levels of difficulty, children as young as three and four years old, as well as undergraduate and graduate students in college may use the software. The most basic levels are referred to as Pilot 1-4, and the more advanced levels of programming are referred to as Inventor 1-4. The software also enables students to record data and report on the data. The level that includes these capabilities is referred to as Investigator.

Figure 2 *Programming screen of Inventor level of ROBOLAB (taken from www.ceeo.tufts.edu/graphics/robolab/motorandlight11.htm)*



Why are forms of robotic technology, like LEGO Mindstorms and ROBOLAB useful? Work with robotics engages a person in active design and helps in the application of computer technology within a constructionist philosophy (Bers et al., 2002).

Methods

This section will give an overall description of the after school robotics workshop, in addition to detailed accounts of each session. Details of the sessions will include the goals for that session and the planned activities and challenges. The section will conclude with an explanation of the evaluation procedures.

The group and the eleven-week plan

The group of children in the after school robotics workshop was comprised of eight third through sixth grade boys, ages eight through twelve. Children participating in the study were recruited via fliers (see appendix A) administered by the Center for Engineering Education Outreach (CEEO), to families in the Medford/Somerville area who were on the CEEO mailing list. Fliers were also distributed to local schools. The flier described that over the course of the eleven-week workshop, the students would learn basic principles of mechanics and robotics through the design, construction, and programming of LEGO structures. They used ROBOLAB software for the programming aspect in order to make their structures move independently. The flier indicated that the students would explore concepts related to friction, pressure, and programming and that we planned to foster a fun and creative environment in which students would be encouraged to incorporate their own interests in their work with the technology. The flier stated that no previous experience was required. The workshop was held at the CEEO on Tufts' Medford Campus (474 Boston Ave., Curtis Hall, Medford). The two undergraduate Child Development students from the Robotics Academy staffed the workshop. After the first four weeks, an undergraduate engineer was hired to help. Members of the undergraduate course about robotics in education also joined these workshop leaders during some sessions. The sessions lasted from 3:15pm until 5:15pm, but the students had the option of arriving as early as 2:30pm and being picked up no later than 6:00pm. They were held on every Tuesday afternoon in the months of January, February, March, and April, beginning January 21 and ending April 15, with the exception of the weeks of the public school winter break and Tufts spring break. There were a total of eleven sessions.

At the meeting of the first session, the parents of these children were provided with a description of the program, which included our research purposes and procedures.

All forms had been submitted to and cleared by the IRB. Specifically, the consent forms asked that the parents allowed their children to participate in the study and to be videotaped and photographed. We specified that the videotapes would only be seen by the investigators and would not be released for other purposes and that the photographs may be used without names on the internet in the description of our results. Any child whose parent did not give consent would not be included in the evaluation. The consent forms also explained that all information, such as names and questionnaire responses, would be kept confidential (see appendix B).

Our initial vision of this workshop included twelve to fifteen fourth- through sixth-graders with equal gender distribution. We expected that the children would work in groups of two or three, sharing materials and a computer. However, due to a variety of reasons, those who participated were eight fourth through sixth grade boys. As a result of the slightly less than anticipated number of children, they were all able to use their own kits, and there were enough computers available for each child to have access to his own during the sessions.

We ran the workshop in three phases. During the first four weeks, we covered a general introduction to ROBOLAB, the programming software that accompanies LEGO Mindstorms, and building with LEGOs in order to familiarize the boys with the tools that they'd be working with throughout the workshop. During these weeks, we presented specific activities and challenges that required the boys to use ROBOLAB with a level of complexity that increased from week to week. During the first phase, we dealt solely with the LEGO cars that they had each built during the first session. We did not prepare specific questions to ask each boy during the process of exploring the challenges, but rather we asked each boy questions based on his experience with the challenges. These questions were intended to encourage thought and spark curiosity in the challenges and the concepts involved. During the fourth session, we introduced an alternate robotic structure, a music box.

During the second phase of the workshop, the boys began the creation of their own unique robots. These robots were meant to take shape as something personally interesting to each boy. After four weeks of work on their robots, the boys presented them to a small audience of their parents, siblings, and other Tufts students and faculty who were interested.

As a culminating activity during the third phase, which covered a span of three weeks, we used a working model, the tube-crawler, the robot designed and built by Tufts University undergraduate engineers, in order to demonstrate a similar project to their own, but on a larger scale. Therefore, both the children in the after school workshop and the undergraduates in the Robotics Academy were engaged in learning by constructionism. Both groups of students were using a challenge to construct something personally meaningful, while developing a better understanding of the project and the concepts behind it. During the first few sessions, the boys used journals made of construction paper, in which they were asked to write something about each session, like something easy, hard, that they liked or disliked during that day. Then, once they had begun their individual projects, I began to videotape them at the end of each session. I asked them questions about their procedure for that day, such as "I saw that you made a change there. Why did you do that?"

We distributed two questionnaires, one at the beginning of the workshop and the other at the end of eight weeks (see appendix C) in order to compare attitudes about technology before and after having participated in this kind of workshop.

Week by week

Phase 1

The first phase lasted for four weeks and was meant for the boys to get very comfortable using the hardware and software involved in the workshop (see figure 3). We presented them with various challenges, some based on programming and other on design and construction. The challenges were also presented in order to cover basic science and engineering concepts involved in robotics. The questions we asked them about their work were attempts to hear them explain their understanding of the concepts, as well as to encourage them to work out those understandings through communicating them to others.

Figure 3   *Workshop participants working with computers*

Tuesday, January 21

During the first session of the robotics workshop, on Tuesday, January 21, we planned a number of activities. The goals of the session were for the boys to familiarize themselves with the hardware and software and for all of us to become comfortable around each other. While we waited for everyone to arrive, the boys who were present made their own nametags, and played various games unrelated to the LEGOs or ROBOLAB. Then, we gave them each LEGO Mindstorms construction kits to examine. Once everyone was present, we gathered in a circle in order to explain how the materials functioned. We discussed how we can do work on the computer so that it communicates with the LEGO RCX in a way that tells the RCX and the attached structure to do what we'd like it to do. This included the idea of energy transformation, which was one of the science and engineering concepts that they explored throughout the workshop. Then, we discussed the building of a car, and we presented the idea of gears during this time, explaining and talking about how they could be used with the motors, axels, and the wheels in order to drive the car. We told them that they would each be building their own cars, and that their cars would have to withstand the shake test. We described the shake test as holding the car and shaking it moderately without any pieces of the car falling off. The boys began the construction.

About halfway through the two-hour session, we stopped one group of four for a snack break. During the snack break, the boys were asked to fill out a questionnaire about their previous experience with technology (see appendix C). They were told that the answers they gave would help us to write a big paper about using technology to teach. They were also told to just do their best and that if they had any questions about something on the questionnaire, they could either ask us or skip the question. This process was repeated for the second group of boys. After they ate, the boys continued to construct their cars, and they each did a simple programming exercise in order to get their cars moving. This brought us to the end of the session.

Tuesday, January 28

During the second session on Tuesday, January 28, we arranged three different activities, each with a number of challenges involved that required the use of their programmed cars (see table 1). The challenges increased in difficulty, so that a boy who was quiet apt using the materials would continue to have more challenges as he was completing the others, while another boy who was not as apt would work on the more basic challenges until it was time to switch activities. The goals of the session were for them to better familiarize themselves with ROBOLAB and the kit hardware with which they were working, to better understand the concept of friction and inclined plane, and to explore the basic science and engineering principles involved in building and programming a robot. The boys were assigned the activity that they would start with, and they each went to the corresponding stations throughout the room. They were each given a slip of paper that listed the first challenge for their activity. They were instructed to inform me when they had completed the challenge, and they would receive the next challenge.

Upon completing a challenge, I asked that they show me the car in action and that they explain to me different aspects of the challenge. I would ask questions such as "What did you do to make sure your car didn't drive into the Pacific Ocean after it got to California?" or "Why was it harder to drive up that ramp?" One activity included a large floor map of the United States. The challenges involved driving the cars from one state to another and making the cars stop in a particular place for a certain amount of time. Another activity involved three rectangular pieces of wood, each covered with a different substance to make for three very different surfaces. One was covered with contact paper, another with sandpaper, and the third with a rubbery surface that is put on stairs to make them less slippery. The challenges involved adjusting the slopes of the three ramps and determining which ones were the hardest and easiest to drive on. The third activity was an obstacle course. It consisted of a bridge, a tunnel, a foam pit, and bumps in the road, all set up in a straight line. The challenges involved driving their cars as quickly as possible through the course, the cars having to stay in one piece. During the session, each boy took a break for snack. At the end of the session, we gave them each the opportunity to take a Polaroid photograph of their favorite thing of the day.

Table 1 *Activities and challenges during the second session of the workshop*

Activity	United States Map	Three Ramps	Obstacle Course
Challenge 1	How many seconds does it take to drive your car from Virginia to California as fast as you can without driving into the ocean?	Place each ramp flat on the ground. Time your car driving from one end to the other of each ramp. Was there any difference in time?	Program your car so that it drives through or over each item in the obstacle course. How long does it take?
Challenge 2	How many seconds does it take to drive your car from Virginia to California as slowly as you can?	When you put one book under the ends of each ramp, which one is the easiest for your car to drive up? Which one is the hardest?	Change something about your car or its program to beat your best time.
Challenge 3	Drive your car from Virginia to California, and stop on the way in Kansas for 4 seconds.	Now make the ramps steeper by putting more books underneath them. How steep can you make each ramp (how many books underneath) and still drive your car up them?	
Challenge 4	Starting in Pennsylvania, drive your car to Texas and then to Washington state without touching the car at any point during its journey.	Figure out which ramp is easiest and which ramp is hardest to drive down.	
Challenge 5	Pretend your car is a ship or submarine and drive it from the Atlantic Ocean to the Gulf of Mexico without touching any land.	Use the hardest ramp to drive down, and make it as steep as you can. Your car must still be able to drive down the ramp without breaking. How many books did you use?	

Tuesday, February 4

At the third session, held on Tuesday, February 4, there were three different stations that required more advanced programming of the boys' cars. The goals of the session were for the boys to better familiarize themselves with the hardware and software and to understand the difference between robotic autonomy and remotely operated. They would have to be precise with the programming and understand and use the light sensor and the touch sensor in order to complete the challenges. Each station had one challenge, and the boys were given a strip of paper stating the challenge at each station (see table 2).

One challenge took place at a station with white paper taped to the floor in a large rectangular area. The challenge was to program their cars in different ways so that when they attached markers, the car would be able to draw at least two different shapes. The second activity was based on a tunnel. The challenge was to program their cars so that a headlight would turn on while their cars were inside the tunnel and turn off as soon as the car exited the tunnel. The third activity took place underneath a table with two large, solid legs, one on each end. The challenge was to program their cars so that they would drive into one leg, and when their car hit, it would stop and drive in the opposite direction until it hit again and drove in the opposite direction, continuing to drive back and forth in between the legs. Again, the boys took a snack break during the session. During the session, we asked them to write in their journals and to take a Polaroid photograph of something they liked about the session. We encouraged them to write about their favorite and least favorite parts of the workshop, something that was hard or something that was easy, or anything else that related to what they'd been doing.

Table 2 *Activities and challenges during third session of workshop*

Activity	Paper on floor	Tunnel	Under table
Challenge	Program your car so that it can draw at least 2 different shapes (examples are square, triangle, circle, rectangle, etc.)	Add a headlight to your car and program it so that the light turns on while the car is inside the tunnel and turns off when your car exits the tunnel.	Add touch sensors to your car and program it so that when it hits a wall, it will start to drive backwards. Once you have done this, change your car again so that every time your car hits a wall (either forwards or backwards), it will start to drive in the opposite direction.

Tuesday, February 11

The fourth session was held on Tuesday, February 11. The goals of this session were for the boys to familiarize themselves with the higher levels of ROBOLAB. At about 3:15pm, we began the session by gathering around a computer while Diana showed and explained to the boys some aspects of Inventor, a more advanced format for programming than Pilot, the level in which they had previously worked. With the exception of one or two boys, they had not yet used Inventor during the workshop. Diana demonstrated how to use the tool bars and various tools within them in order to make a complete program. We spent about 10 minutes doing this before we set them off to their own computers, challenging them to program their cars to do anything they wished, using Inventor. We intended to get them to the point, after the first hour, at which they could all engage in a race or battle.

After this introduction to Inventor, they took a snack break. During the snack break, Diana demonstrated an RCX playing music. We told the boys that their next challenge was to make a music box and that they needed to use Inventor 3. We assisted the boys in using the music options in Inventor 3 on an individual basis. Their next challenge, once their RCXs played music, was to make something move on their RCX while the music played. At this point, we allowed them to search through several boxes of extra LEGO pieces in order to accomplish the task and to make it fun and personalized. The construction of the music boxes brought us to the end of the session.

Phase 2

During the second phase of the workshop, the boys designed and built robotic projects that were entirely based on their own interests. They had four sessions to work, followed by an opportunity to present their projects to a small audience of their families and Tufts' students and faculty who were interested in their work.

Tuesday, February 25

The fifth session occurred on February 25. The goals of this session were to get the boys thinking about and working on robotic projects of interest to them. Another undergraduate student-helper was there for the entire session. She was hired by the CEEO in order to help us manage all the needs of the boys. She was an engineering student and had some experience working with children and ROBOLAB. She helped out for the remainder of the sessions. At 3:30, although three of the boys were not present, we began by explaining that they would be starting their own projects. We told them that they would have decision-making powers over what they worked on. Then, we gave them some examples of potential projects by showing them what other people had made using LEGOs and ROBOLAB. We showed a video clip of the robotic animals that students of an undergraduate engineering course had made at Tufts University.

Next, we presented some photographs of other robotics project, including a music box with dancing figures, two different windmills, and a LEGO sorter. We then asked the boys to share some of their own ideas. Then, they returned to their kits with their journals, and we asked them to write down a brainstorm list or draw pictures of their ideas. Finally, they began to create. They worked on their individual projects for the entire session, with a snack break when they were ready for it. At the end of the session, I videotaped each work-in-progress, asking the boys some questions about their projects. I asked questions such as, “Will you explain your robot?”, “What does it do?”, “What was the hardest part about working on it today?”, and “How did you solve that problem?”

Tuesday, March 4

During the sixth session on March 4, the boys continued working on their own creations. The goals of the session were for each boy to explore the issues related to the design and construction of his personal robotic project. The student-helper was not with us, as she was sick. Some of the boys finished working on what they had intended for their projects, and we encouraged them to expand the projects by asking them what else they could add and by giving them some suggestions. We had a snack break halfway through the session at which point we announced and explained that we would have a presentation day on March 25 for the families of the boys and for the people who we knew were interested in the boys’ work. We told them that they would have the first hour to polish their projects and that during the second hour they would present their projects, telling us some things about it, like what the hardest thing was, why they wanted to do that project, why they liked their project, etc. The boys finished the session by continuing the work on their projects, a couple by switching project ideas all together and starting anew. Again, I videotaped them at the end of the session giving their explanations about what they had done during the session, what their ideas were, what the hardest thing was, etc.

Tuesday, March 11

The seventh session of the After School Robotics Workshop met on Tuesday, March 11. During the session, the goals were to continue adding to their projects, in form and function and to engage them in structured analysis. They worked independently during the first hour. After their break for snack, we gathered them and went around to each boy and his work. Each boy explained his project and his plans for the project. We asked for suggestions from the other boys, and after we finished, each boy went back to work, some basing their next steps on the suggestions of the others. Again, I videotaped their projects and their responses to some questions about the work that they had done throughout the session.

Tuesday, March 25

Tuesday, March 25 was presentation day in the workshop. A group of the boys' parents, siblings, friends, and Tufts-related people who were interested came to the CEEO in order to watch the boys present their robotic projects. The goals during the first hour were for the boys to get their projects to a point at which they were comfortable presenting them to the group. During the presentation, the goals were to engage the boys in conversation about their projects in order to know more about their thinking processes and what they had learned from doing their projects (see figure 4). Another important goal was to make the boys feel that their work was valuable and interesting to other people.

Figure 4 *Boy presenting his project*

During the first hour they continued work on their projects, fine tuning and polishing what they had already completed. At 4:30pm, we set up the room for the presentations, had a short introduction to welcome the audience and to remind the boys to fill out the second questionnaire at the end of the presentations (see appendix C), and we began the presentations. Each boy spent about five minutes talking about his project. We videotaped the presentations, and I asked questions about their initial ideas, what they had changed, why they had made changes, the easiest part of the project, the hardest part, the most fun, etc. We videotaped all of the presentations. After the presentations, I handed out the questionnaires that the boys completed while they ate pizza and had drinks that we had provided. This also gave the parents a chance to ask us some questions and to give us their feedback.

Phase 3

The third phase of the after school workshop was meant to incorporate the principles and concepts behind the Robotics Academy tube-crawler into the curriculum of the final three weeks of the workshop. These concepts included energy transformation, friction, programming, robotic autonomy vs. remotely operated, structural analysis, and tension. The boys were presented with a similar challenge to that which was presented to the engineers of the Robotics Academy. We also intended to provide evidence that robotics is a valuable field in everyday life.

Tuesday, April 1

The first session of the third phase took place on April 1. All eight boys were present. The goals were to engage the boys in an engineering design process in order to create robots with specific purposes. In order to work toward the goals, they would also have to use more advanced design and programming of their robots than was previously required of them. We began the session by introducing the LEGO cameras that each computer had attached to it. Then, we talked about the camera and the important things to keep in mind when using the camera. We asked the boys to build robots, in pairs, that could navigate tunnels. Since the tunnels we constructed out of poster board had turns in them, the boys' robots had to have the capacity to make turns. The boys were given the opportunity to use their paper journals to write down or draw ideas. We videotaped the session.

Tuesday, April 8

On April 8, the second session of the third phase took place. Seven boys were present during this session. The goals for the session were for the boys to have success in the building and operating of a robot that could navigate pathways. The boys navigated their robots through a model of the Titanic that was present in the CEEO because another group had used it for a similar project (see figure 5). The boys were given the option of using the program that we provided that enabled them to use touch sensors as remote controllers, or they could use their own programs. They were also given the option of working in partners or independently.

Figure 5 *Model of the titanic*

At about 3:30pm, when all the boys had had a chance to work for a few minutes on their robots, Matt Dombach, the engineer who was there from the Robotics Academy talked to the boys about the Robotics Academy's LEGO version of the tube-crawler. He explained how and why they built it in the way they did, and he described some real life applications for it, like for looking around in pipes and for looking around in someone's body. Then, he demonstrated how it navigated the Titanic, and he allowed the boys to try using it. For the remainder of the session, the boys built, programmed, and used their robots in the Titanic to search for artifacts that had been planted there by the people who built the model. They were given a list of all the artifacts that they may have found and they had to use cameras that they had placed on their robots in order to find the artifacts and decide what each one was. There was a snack break, and the session was videotaped.

Tuesday, April 15

The final session took place on Tuesday, April 15. The goals of the session were to give the boys a last chance at operating their tube-crawlers and to wrap up the workshop. When the boys arrived, we encouraged them to work a little more on their tube-crawlers. We gave them the choice to do some additional navigation of the model of the Titanic or to do a new activity that we had designed. The purpose of the new activity was to get the boys to use the feedback that they received through the camera in order to control their tube-crawlers. We did this by challenging them to find and report on a picture that had been taped to the floor and was surrounded by opaque walls and ceiling. This required them to position their cameras so they were pointed at the floor, and it also challenged them to use only the information they received from the camera picture, without using their own senses to observe the tube-crawler or the picture.

We had a variety of pictures, with subject matter of animals and sports items, which we rotated one-by-one after each successful identification. We surrounded the pictures by high poster board that was standing up, with a poster board as a ceiling on top of it, so that it was impossible to see the picture inside. We positioned each boy or group's tube-crawler at a small opening on the opposite side from which the boys were, so that they still couldn't see the picture, and their tube-crawlers were heading inside. We also had to position a lamp inside the poster board with the pictures, since otherwise it was too dark for the cameras to pick up a good picture. At about 4:30, pizza arrived, which began our wrap-up of the workshop. Once the boys had finished eating pizza, we gave them one final opportunity to do the new activity or to navigate the Titanic, and then we asked them to sort their LEGO kits. This brought us to the end of the session and the end of the workshop.

Evaluation

Evaluation of the effectiveness of the After School Robotics Workshop was completed in a number of ways. All data used in the evaluation was qualitative. We used a comparison of two questionnaires, filled out by workshop participants (see appendix C). These questionnaires addressed the boys' backgrounds with technology and robotics and attitudes about technology and robotics. The first one was distributed and filled out at the first session. The final questionnaire was completed after eight sessions of the workshop. We also used observations as a means of evaluation. We made notes of our observations, and we collected the observation notes of the members of the Child Development course who came for the purpose of observing the workshop. We also used video documentation as a way of preserving the sessions for post-observations, and we considered the written observations of the students from the Robotics in Education course. In addition, we used the video journals and the boys' individual projects and their descriptions of them as a means for judging the depth of their understanding and their abilities in using ROBOLAB.

Results

This section will report on each session of the after school robotics workshop, based on how the session turned out in reference to the expectations for that session. It will also report the findings from the observations and evaluation measures.

Week by week

Phase 1

The boys increased in skill level with each session. They arrived at very different levels, starting with very different backgrounds in robotics and technology. They became much more comfortable with the materials and with asking us about how to do certain things. They also became much more self-sufficient throughout the four weeks of practice with ROBOLAB and the Mindstorms construction kits.

Tuesday, January 21

We loosely followed the agenda for this session. The boys arrived between 2:30pm and 3:20pm. This was a long period of time for those who arrived early to wait without working with the robotics materials. The nametags only took a couple of minutes for them to make, and during the rest of the down time they seemed quite antsy and bored. We had planned that the boys would work in teams of two, but we had plenty of construction kits, so we gave each boy his own. While we talked about the gears, the boys seemed very bored and ready to start working with their kits. They jumped right into the building of the cars, and most of them did not use the gears after we had explained how to use them. We broke the group up into two smaller groups of four in order to eat snack. This seemed to work well. They were all very cooperative in the filling out of the questionnaires during their snack break.

After the snack break, we expected that the boys would fill the remaining time by putting together their cars. However, the bricks had a couple of programs that were pre-programmed into them, so the boys were able to operate the bricks without using the computer. So, once they witnessed the bricks operating the motors that moved other pieces, some of them wanted to know how to do the programming so they could control how the motors and other pieces would move. So, we helped the boys on an individual basis, showing the ones who were ready how to go into ROBOLAB and use some basic aspects of the programming. The boys worked on their cars and basic programming until their parents arrived to pick them up. The most difficult things were trying to accommodate all of the boys between the two of us, and trying to adjust to the big discrepancies in their skill levels and comfort in working with the materials. Since I didn't know the answers to many of their questions, I often answered them by asking, "What do you think will happen?" and "Why don't you try that out and see what happens?"

Tuesday, January 28

During this session, the boys engaged in several challenges at three different activities. There were the eight boys from the first week, with the addition of one, for a total of nine boys. We expected that they would work in equal size groups at each of the three stations for one-third of the session, and then rotate all at once. However, due to the differing speeds and interests of the boys, we allowed them to switch activities when they felt ready. No one completed all the challenges at the map activity, but they seemed to enjoy the initial ones that they worked on. The first three challenges at the map station were very appropriate, and they got to know the programming procedures much better in their attempts to complete the challenges. Challenges four and five at this station were too difficult because, since we encouraged them to build their cars in any way, many of their cars were not capable of making tight turns or any turns at all.

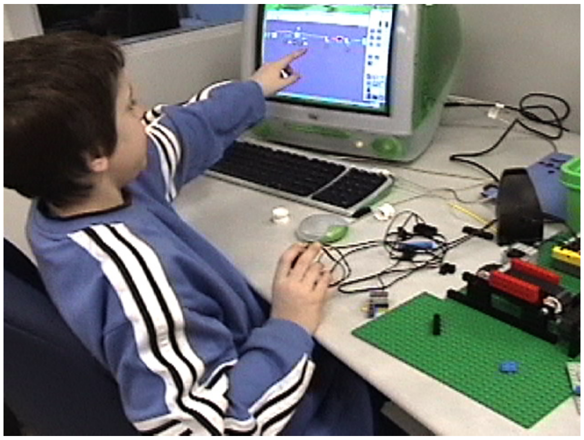
The ramp station kept the boys busy for long periods of time. They did well with the first three challenges, but only one or two boys made it to the fourth and fifth challenges. Since they were trying to find out the amount of time it took to drive on each ramp, without our prompting, they paired up and asked the other boys to time their cars, so that they were interacting with one another. When I asked them questions about why it was easier for their cars to drive up one ramp than another, they very clearly explained the concept of friction and its relation to inclined planes, sometimes using the actual words and other times giving an accurate description without using the word. They also demonstrated knowledge about the programming, that they could increase and decrease the speed of the motors, and they even discovered that sometimes a car could make it to the top of a ramp at the slowest speed but it wouldn't go anywhere at a faster speed.

They really seemed to enjoy the obstacle course, as most of them stayed and worked at it for a long time. It was very challenging for them for two reasons. First, most of their cars did not drive in straight lines, and the course was set up in a line. So, they had to use trial and error to figure out where to position the car at the start line in order to hit every obstacle. Also, their cars often fell apart when they drove over the bumps. So, they had to do more to the construction of their cars in order that they could withstand the bumps. We learned more about the boys as individuals with unique interests, abilities, and styles. One boy will not ask questions even when he needs help, so it's important to approach him regularly to check on his progress. Another boy enjoys and is skillful at advanced programming but needs to be reminded to apply his skills to the task at hand that the rest of the group is working on. We did not document this session, but it would have been very helpful.

Tuesday, February 4

One boy was absent during this session and for the remainder of the sessions, totaling eight boys. They engaged in three different activities. Each activity required that the boys used more advanced programming than they previously had (see figure 6). Again, we allowed them to choose the station at which they started and to switch activities when they felt ready. With the exception of one boy who was determined to complete a challenge before moving on, most of the boys were eager to spend time at each activity, often leaving one before they had really gotten anywhere with the challenges. The tunnel challenge was difficult for the boys. Most of them were able to get their lights to turn on, either by doing the programming for it or by attaching the light and using the program that was already programmed into their bricks that worked the light. However, no one was able to get the light to turn off when their car exited the tunnel. So, they weren't able to get their light sensors working, in part because we couldn't figure out why they weren't working either.

Figure 6 *Boy programming his robotic structure*



The challenge of drawing shapes onto the paper that lined the floor did not appeal at first to any of the boys. However, after working at the other two stations, some boys attempted it. All the boys who attempted the challenge used their cars to draw circles. They programmed their cars so that they would continuously spin. None of the boys attempted to use the programming to stop the cars in place, turn it, and continue drawing in a different direction, which would have created a shape other than a circle. For some, the programming would have been too difficult, and for others, their cars were not built so that they could make those kinds of tight turns in place. For instance, some boys built their cars so that the back wheels were powered by one motor and the front wheels were powered by one motor. In this case, they were not able to make their cars turn. So, the activity was a bit advanced. During this session we had to spend a lot of the time fixing things that were broken and retrieving extra pieces.

The boys did well with the touch sensors in the bumper car activity. Many of them were able to get their touch sensors to work properly in conjunction with their cars. This was easier for them than the light sensor. The biggest problem they came across was that their touch sensors would break off their cars when they hit the walls. So, they built stronger supports for their touch sensors and slowed down the speed of their cars. Again, they demonstrated an understanding of science, in the relationship between force and speed. While they waited for their parents to pick them up, they used their cars to battle one another, and they enjoyed this very much. Today there was a shortage of computers because there was always at least one that wasn't working. This was tough for the boys because they had to wait and then move out of what another boy was working on, and then he had to come back and do the programming again because his was erased.

Tuesday, February 11

We found during this session that many of the boys had difficulties using Inventor. One of the biggest problems was the fine motor skills that the upper-level programming required. The level necessitates precise movements of the mouse in order to manipulate and string together small pictures on the screen. We had planned to get them competing in either a race or in a battle between their robots after about an hour, but they didn't quite get that far. In fact, by the end of the first hour, some of them hadn't even programmed their cars to just simply go. They were very interested in the many additional tools that Inventor offers, which kept them occupied, so they didn't need a larger goal.

After the snack break, we introduced the musical abilities of the RCX, and we challenged them to make their own music boxes. In order to do so, they had to use Inventor, level three. Again, the programming was difficult for them, but they were all able to play music on their RCXs. The boys really enjoyed the introduction of the new LEGO pieces. They spent most of the remaining time shuffling through the tubs of

LEGOs, and some of them continued with the challenge of making something spin while music was playing. These boys chose pieces from the tubs that interested them and used the pieces as their spinning objects. By offering more opportunities to focus on the aesthetic aspect of the design process, we were able to see which boys really enjoyed that portion.

Phase 2

This phase offered the boys a chance to focus solely on their interests within robotics. They worked individually for four weeks, constructing robotic projects of their choosing. Many continued their work on a project that they had begun during the first session of this phase, while others spent some time on one project, decided they had invested enough into it, and changed projects. At the end, the boys' families, Tufts students and faculty, and we provided an audience for the presentations that the boys gave about their projects.

Tuesday, February 25

During this session, we had a student helper, who was hired by the CEEO. Despite the abundance of helpers, the boys didn't need much assistance throughout the session because they were in the beginning stages of their individual projects. The brainstorming session wasn't very successful because the boys who had ideas were ready to get started on them, rather than just talk about them, and the boys who didn't have ideas couldn't add any to the brainstorm list. A few of the boys wrote in their journals after they had been introduced to some possible projects, naming their ideas or drawing them, but many of the boys were eager to get started on the building and programming.

The boys all worked entirely on constructing their ideas during the session, and only a few had time to do some basic programming.

The student that the CEEO hired to help us had a very different style with the boys than the way that we had been conducting the sessions. She was much quicker to give the boys a concrete answer than we were, and she didn't delay by trying to prompt them to figure the answer out. On the other hand, there was a student there from the Child Development course who used a similar style to ours. The boys began work on projects such as a tank, a series of conveyor belts, an escalator, a jack-in-the-box, a catapult, and a robotic arm. I began to use the video camera in order to tape them talking about their projects, as a sort of design journal. The boys were very willing to engage in conversation about what they had done, and it got them thinking about their projects and some of the concepts involved. Their answers showed some really deep and complex thoughts about the mechanical aspects of their projects, as well as the engineering design process. At times, it seemed that there were too many helpers, as they had plenty of time to sit around and do nothing because they were trying not to harp too much on the boys.

Tuesday, March 4

At the sixth session, seven boys were present. Also, our CEEO student helper was not there. Some boys worked very diligently throughout the entire session, seemingly very engaged in their projects. Other boys seemed bored by what they were working on. One boy who hadn't been there the previous week began his project during this session. He had an idea of a music box with spinning boats, but he was concerned about how he would handle the issue of water. We suggested that he use LEGOs to make an area that looked like water. He was a child who needed more direction from us than some of the other boys. For instance, after witnessing his problem of a spinning figure that was hitting a gear, I said, “What can you change about where the horse is so that it doesn’t hit the gear?” He didn’t know. So, I said, “What if you made it higher?” At that point, he got it and began trying to make it sit higher. However, he had a really hard time getting it to sit higher, and when his first idea didn’t work, he didn’t know what else to try. So, I said, “What if you used another piece from your kit to connect these two together so that it becomes higher?” Then, he came up with a great idea, that I never would have thought of, and used the worm gear as an extension piece in order to prop up the horse.

During this session, I worked one-on-one with another boy who had built a conveyor belt system and was grappling with the idea of adding on to it. When I asked him if he wanted to try and add something else, he responded that “Sometimes, when you try to make something perfect and you do make it perfect and then you try to make it more perfect, it just doesn’t work very well, and then you can’t remember how you did it before to make it perfect.” He explained an aspect of the engineering design practice in a way that it pertains closely to everyday life. Another boy was struggling to get his robotic arm functioning. He knew that there was too much weight for the motor to lift, but he didn’t know how to fix the problem. I offered to ask some engineers if they had any advice. We introduced the idea of the presentation day, and the boys didn’t give much of a response. The parents were delighted to receive the presentation day invitations at the end of the session. One boy had worked enough on his catapult and decided to build a car that could battle against other robots. Another boy abandoned his original idea for a new one, a spinning claw that could pick things up or knock things down. After some discussion about his robot, he told me that he had put many axels around a central axel because the outside ones were providing support and strength. The boys tended to pursue ideas that they knew they could address in a relatively short amount of time.

On several occasions, we asked boys what they thought they could add to their projects. In most cases, the boys didn't know or have any ideas that they shared with us, but other boys who heard us talking would give some ideas on how he could expand his project. This happened often, that when one boy didn't know how to build onto his project, another boy would get excited and give some ideas about how he could expand his project. This led to the original boy's return to working on making some of the changes that were suggested (see figure 7). Again, the helpers were not always busy with questions.

Figure 7 *Boy determining the cause of a problem with his project*

Tuesday, March 11

During this seventh session, we could again make out a significant difference in teaching style of the student hired by the CEEO and our teaching style. When she heard a new idea, she immediately pointed out the things that the boy would have to account for in carrying out that idea. We had the boys each take a look at others' projects and listen to their peers explanations of the projects. Not only were the boys pleased to share their work with others, the boys had many great suggestions for their peers about what they could add, change, or do differently with the projects. They suggested that one boy use his car to try to drive up walls. They also proposed that another boy make his boats spin more slowly so that they could see them better. One boy mentioned that his peer could use a touch sensor in his catapult, so that it flings things automatically, whenever something lands in it. The boys showed equal excitement toward projects that utilized more complex construction and programming, like the robotic arm, as they did toward more simple projects, like a conveyor belt. After sharing their work and their suggestions with their peers, they each settled back down into their own projects, seemingly more engaged than before they had done the sharing with each other.

Tuesday, March 25

The first hour of this session was for final preparations for the presentations. Some boys were ready for their presentations and didn't want to or need to make many changes to their projects beforehand. Other boys worked diligently in the remaining hour before the audience arrived. While the boys were in front of the audience presenting their projects, they talked comfortably and knowledgably about their work (see figures 8 & 9). During the presentations, I asked questions such as, "What have you changed since you first started working on it?", "Why did you make those changes, and what advantages did they give you?", "What was the easiest part of your project?", "What was the hardest part of your project?", and other thought-provoking questions. After the conclusion of the presentations, the boys were given the post-questionnaires to fill out (see appendix C). The parents stayed for a little while and asked us many questions about the workshop, ourselves, and other similar workshops that will be offered in the future.

Figure 8 *Boy presenting robotic arm*

Figure 9 *Boy describing is original idea*

Phase 3

The phase gave more structure to the boys' work than the previous phase had. The boys first worked in groups, and then chose to work in groups or individually, to create tube-crawling robots using the LEGO cameras, for the purpose of navigating pathways such as the inside of the model Titanic. They were also introduced to the Robotics Academy tube-crawler and some potential uses for it, and they were given a chance to test it out inside the Titanic.

Tuesday, April 1

The set up of this session was different from the following sessions because the space we generally used was unavailable. We were in a room about one-fourth the size of the previous room. During the very beginning of this session, the boys enjoyed seeing the cameras, and they easily described some of the drawbacks associated with using the camera, such as taking into account the tether, the discoloration of the picture on the computer, and the delay from the actual event to when the event occurred in the camera view on the computer (see figure 10). They paired themselves up, with minor difficulties, and they went to work. Some pairs argued about how to design the robot and what each boy's job would be. Many of them expressed frustration with their partners.

Figure 10 *Boys are introduced to the LEGO camera*

Three of the four pairs had a hard time working together. In two of the pairs, one of the boys was at a much higher level with the materials and did most of the design and programming, leaving little for the other boys to do. For one of the groups, I suggested that one of the lower-level boys be in charge of the design. This seemed to appease both of them, but at the end of the session, the boy who was doing the design said, “I didn’t do anything. He didn’t need me.” They also had a lot of difficulty with the task. Most groups did the building first, followed by the programming. They had a lot of trouble programming their robots so that they would turn when pushed the touch sensors. So, they worked for the entire session, with the exception of a short snack break, and only one of the pairs finished with a robot that moved straight, to the left, and to the right, according to which touch sensor they pressed. The other boys were frustrated, and one told us that he didn’t like this project. Another told us that he liked the individual projects better because he knew his own skill level and could work within that level. He said that these robots were too hard for him.

Tuesday, April 8

During this session, two partnerships decided to remain intact from the previous week, while the remaining three boys who were present worked independently. One pair used their own program, as they had gotten it to work the week before, but the others used the program that we offered them. The pair that had the functioning robot from the earlier session worked very well together, splitting up jobs for each step in the process. By the final step, using the robot to navigate the Titanic in search of artifacts, they had the partnership mastered, as one was watching the computer screen for the picture that the camera transmitted, and he was telling the other boy, who was operating the robot, in which directions to go. This group did the most thorough investigation of the Titanic. The other pair struggled to decide who would do which task, and were frequently arguing. The boys listened very intently to Matt Dombach, during his explanation and demonstration of the Robotics Academy tube-crawler (see figure 11).

Figure 11 *Robotics Academy student*

They asked thoughtful questions, such as “How did you wire the game controller to the robot?”, and one boy commented upon seeing Matt’s robot, “Oh, it’s the same as ours.” He realized that Matt’s robot was designed for the same purpose as theirs were, the navigation of curvy pathways. Throughout the rest of the session, all the boys were able to practice with a robot in the Titanic (see figures 12 & 13). Two of the boys who were working independently had a very difficult time with their own robots, so these boys chose to use the Robotics Academy robot for a portion of the session instead of their own. The biggest difficulty was that we had to have computers directly next to the Titanic in order for the boys to be using them to obtain the picture that the camera transmitted, and we were only able to have two of these computers setup. So, some boys had to wait while others were using the computers.

Figure 12 *One group's tube-crawler*

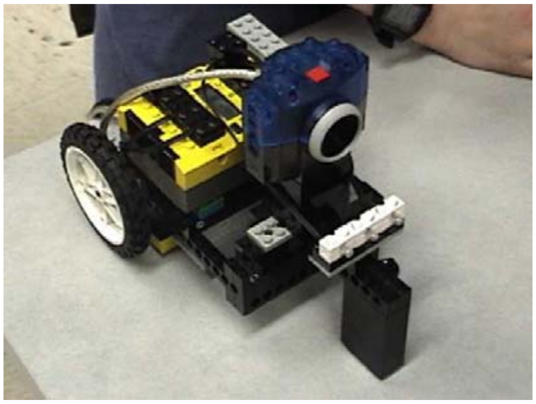
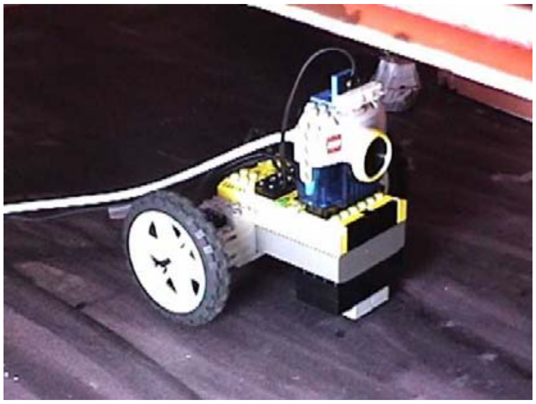


Figure 13 *Another tube-crawler*



Tuesday, April 15

During this session, each boy or group did something different. One boy did not want to do anything further with his tube-crawler, so we challenged him with the new activity. However, he was overwhelmed by the idea of trying to make the camera look downward, and he was getting frustrated because his tube-crawler was constantly falling apart, almost every time he ran it. So, we suggested that he do the new activity but with the pictures taped to the inside walls of the poster board, instead of to the floor. That way he would not have to move the position of his camera at all. He agreed, and we set it up. He did really well with the activity and was encouraged by his success. He was disappointed when he had to let other boys have a turn, but he told me that he really liked the activity and that it was something he could do. Then, he stuck around while other boys did it. One of the pairs eventually finished navigating the Titanic and tried out the picture activity, with the pictures taped to the floor. They also had success, working together by both watching the computer screen for the camera pictures. The boy who was not driving the crawler was giving the other one directions. For the most part, the boys seemed a bit restless, especially right before the food came, as they were very hungry and they weren't entirely enthralled in the activities. After eating, some boys sorted their LEGO kits diligently, while others used the time to fit in some final minutes of play with the materials.

General observations

In sum,

- Boys reported general technology and typing as easier at the end of eight weeks
- Boys displayed comprehensive understandings of science and engineering concepts through their descriptions and explanations of their projects
- Boys experienced the having of powerful ideas and reported on these ideas in the video journals

We were able to collect questionnaire data for eight boys. Comparing the pre- and post-questionnaires made for an interesting discovery (see appendix D). More boys reported the categories of general technology and typing as easier than they had originally reported, after having participated in eight weeks of the workshop. However, more boys reported building a robot as harder than they had reported it being before the eight weeks of workshop sessions.

Our own observations have noted the boys' comprehensive understanding of science and engineering principals through their interactions with and dialogue about ROBOLAB. During the session on Tuesday, January 28, I had a conversation with a boy who was involved in the Three Ramps activity. He showed me which ramp was easier for his car to drive up, and when I asked him why it would be easier on that one, it was clear that he had already formulated a reason for this. He explained that the surface of the ramp was rough and the surfaces of his wheels were also rough, so that when they touched each other they were better able to get a strong grip, and thus his car could more easily climb a steeper incline.

Observations from members of the Child Development course have also indicated proof that the boys are learning to a great extent. One student, in a paper about her observation experience, describes an interaction between two of the workshop participants. One boy had asked another boy why he had attached all the gears to one another. The other boy answered **"Because I want the ships to spin in sync with each other so they're all going fast."** The student pointed out in the paper that this boy was not only learning about speed and force, but he was also teaching his peer about it. Another description of an interaction details a situation in which one of the leaders asked a boy what he could do to make his catapult launch an object farther. The boy responded, **"I can make the motor go faster so the launch will have greater force."** Again, the project and the boy's motivation to do certain things within his project led to discovery about science and engineering concepts.

Apparent in the boys' video journals was the complexity of the thought processes behind their projects. They created robots that integrated a variety of principles of science, while having practiced the engineering design process. The boys' descriptions of their projects and the concepts behind them evidenced their experiences having powerful ideas. They gave explanations that were meaningful to themselves because they had discovered them through the construction of their robotic structures, so it made sense and was important to them. The ideas were also important science and engineering concepts. The boys seemed to enjoy reporting about their experiences through video means to a much greater extent than they had the paper and pencil method. They were able to speak with ease about their projects and processes, and they could use the physical construction to support their verbal descriptions by pointing things out. For example, one boy was asked “How did you make the boat move that way when the conveyor belts are moving the other way?” He responded while demonstrating each of the actions, that **“This is some kind of teeth, and then I put this thing in here like, uh. See, when it goes that way, it turns this which goes around, which pushes it out. See, it pushes it out like that.”** His working through of each step in the process demonstrated his understanding of it. Therefore, video journals were the best means by which to support and enhance the learning and discovery.

In another video journal, one boy was asked to talk about the hardest thing in the work he had done that day on what he called a rotating claw. He said, **“Probably getting this to not be very much weight. I was using bigger ones so that it would weigh more weight, so then I used the little black ones.”** Then, he was asked why it didn’t work when it was heavier, and he replied, **“It was really wobbly in my hand and the weight caused it to not really move, it just went like that [he shows where it got stuck in the rotation], and so then I made it lighter, and now it works.”** A third boy talked about his project and said, **“This motor’s not strong enough to lift the whole arm up.”** He was asked what he had tried to do to make it lighter, and he responded, **“I stripped down everything that’s possible…It makes it go a lot slower and easier to handle…”**

Discussion

This section uses observations in order to tie the experiences of the boys in the after school workshop to the Massachusetts Curriculum Frameworks and to state a case about the relevance and value that ROBOLAB has in an educational environment.

The after school workshop environment

The after school workshop environment offered many benefits in terms of an educational setting. First, the curriculum was entirely decided by the people running it. Thus, there was tremendous freedom in the execution of the after school workshop. There were no mandates about what or how the children should be learning, and there was no test that children had to pass at the end. These were the things that aided us in our attempts at testing the value of robotic technology in an educational setting. Perhaps similar workshops could be held at schools as a way of phasing this type of technology into the curricula during school hours. More research is needed in order to determine the best way to bring technology into schools.

In order to implement this technology into schools, one should know that a group of eight third through sixth grade boys required immense energy and attention. We found that the boys required our help to a great degree. When we were only two helpers with all eight boys, we were constantly darting from one boy to the next. However, when there were four helpers for eight boys, we felt very well covered. Depending on the phase of the workshop, the boys needed more or less assistance. At the beginning, when they weren't very familiar with the hardware or software, they needed our help in many ways. As they progressed through the sessions, becoming more and more familiar with the materials, they needed us less and less often. However, when we weren't able to give them help right away during the first phase, they tended to get bored with what they were doing and move on. It is also important to keep in mind that during the second phase they were working on their individual projects, very different tasks than they were doing in the first phase. So, perhaps they didn't want or need much help when there weren't any clear goals or expectations, but they wanted and needed the guidance more when they were challenged to meet specific goals. They may have thought that they need the help because they saw the answer or result as something that could only be arrived at in one way. However, that was the beauty of a technology such as this. Children were encouraged and expected to figure out multiple ways of accomplishing a task.

Leading a group of youngsters in the use of something technical like robotic technology made individual capabilities and difficulties with the technology apparent. The boys were at such different levels, yet because of the nature of the technology and the setting, they were all able to successfully use and benefit from the technology. However, this often required that we adjust the activities for certain boys, in order to match their abilities. For instance, during the final session on April 15, we had to tape the pictures to the wall for one boy, since he couldn't fathom attaching his camera so that it would look down, and to the floor for other boys, since the activity would be too easy for them otherwise. Not only did capabilities and difficulties become apparent, but also different learning and personality styles. Some boys had to master a challenge before they moved on to the next challenge or activity. However, others were not interested in completing the challenges, but only in attempting them, and then they wanted to move on to the next activity. We had to constantly come up with ways to be sure the boy who worked at the highest level continued to be challenged, while the boy who worked at the lowest level could keep up to some extent. The challenges of increasing difficulty during the first few weeks accounted for this difference, but throughout the rest of the workshop, we had to approach each child with his level in mind. While they worked on their individual projects, we had to remember to make suggestions that were appropriate for that child and his project. Some of the boys were energized by big ideas, while others were overwhelmed and discouraged by them and could handle small changes much more easily.

When combining technology and children, we had to keep in mind several important facts. First, we had to adjust the plan depending on how the children reacted and performed. We found that the boys had a hard time operating the mouses. Therefore, we switched the mouses of the boys who were having the most trouble with it, to other mouses that were more easily manipulated. The boys also had a much easier time understanding and using the touch sensor than the light sensor. Perhaps this was because the touch sensor only had two options, whether it would place its effect when the button was pushed inward or when it was released outward. The light sensor was more complicated and offered a spectrum of settings, which may have been confusing to the boys.

Guidance for the children throughout their use of this kind of technology was very important. We tended to use a constructionist approach, by prompting the children along on their own paths of investigation and discovery. We refrained from telling the children what they should do, and we encouraged them to talk out their own answers to their questions. Our approach was contrasted by the approach of the CEEO helper, who used a more instructionist style, by giving the boys explicit instructions about what they should do next. When I asked some of the boys who had interacted with the helper why they did what they did, they said, “Because she told me to.” However, when I worked through a problem with them, allowing them to lead in coming up with an answer, they could always tell me why they had done something. I also found that the boys came to Diana and me more often with their questions than they did to her; however, this could be due to a greater comfort with us and not necessarily related to our styles.

We also had a difficult time balancing the number of helpers with the amount of help that the boys needed. I expected that since they were all working on the same activities during the first several weeks, they would all have the same questions and either work them out together or we would explain things all at once. However, it did not work that way, and they worked on relatively individual bases, all coming to us separately when they were stuck at something. We should have had more helpers in the first three weeks when the boys were just learning how to use the materials. Then, we could have cut down in the remaining weeks because they didn’t tend to need a lot of help on their individual projects. I would have expected that they would need more help during these weeks because they were all working on something different. However, they worked at levels that were comfortable for them, they were more familiar with the materials, and they used each other a lot for help.

During the third week of the individual project construction, the boys visited each other’s projects and listened to their peers talk about what they had been working on. They were very receptive to their peers’ information, they were very willing to share their own information, and they were very eager to give suggestions to one another and to accept the suggestions of the others. This was a technique that we could have used during each of the weeks that they worked on their individual projects, as well as during the initial weeks of activities and challenges. The more they talked about their work, the more they verbalized the science and engineering concepts involved, and the more accurate these verbalizations became.

We changed from paper and pencil journals to video journals because the boys enjoyed talking about their work at the end of the sessions, and they were expressing their understanding of the concepts involved and their ability to work with the LEGOs and ROBOLAB. Their descriptions made their having of powerful ideas apparent. These ideas revealed concepts that were important in the domains of science and engineering. Many of the concepts that they came to understand to a great degree through their personally significant projects were concepts that were specified by the Massachusetts Curriculum Frameworks as subject matter that must be mastered by elementary children in the state in the areas of science and engineering (see table 3). Therefore, in this workshop, ROBOLAB promoted the discovery of powerful ideas, ideas that are meaningful to the person discovering them and valuable to a certain domain. Since many of them are listed in the Massachusetts Curriculum Frameworks, ROBOLAB can lead to the learning of many concepts mandated by the state frameworks.

Table 3 *Science and engineering concepts displayed in projects and activities of the robotics workshop and their relation to the Massachusetts Curriculum Frameworks*[2]

Science/ Engineering Concept	**Definition**	**Projects or activities that displayed concept**	**Massachusetts curriculum frameworks application: Science and Technology/ Engineering Sections**
Lever	A straight platform that rests on a fixed, elevated point, the fulcrum, in order that one end of the platform can be moved so that the opposite end is able to move an object more easily	• Robotic arm • Conveyor belt with catapult	• Properties of Matter section of Physical Sciences, Grades 6-8 • Simple machines in Technology/ Engineering Section, Grades 3-5
Inclined plane	A flat surface that is at an angle so that one end is higher than the other because less force and energy is needed to move things up or down at an angle than straight up or down	• Inclined conveyor belt • Amusement park with roller coaster ramp (see figure 14) • Three Ramps activity on January 28	• Motion of Objects section of Physical Sciences, Grades 6-8 • Simple machines in Technology/ Engineering Section, Grades 3-5
Wheel and axle	An axel is a rod that is placed at the center of a wheel in order to make it turn, making it easier to move things that sit above the wheels and axels	• Car with gears (see figure 15) • Conveyor belts and their spinning systems • Amusement park with spinning rides • All activities involving vehicles such as cars	• Motion of Objects section of Physical Sciences, Grades 6-8 • Simple machines in Technology/ Engineering Section, Grades 3-5
Screw	An inclined plane that continuously raps around itself in order to lower or raise things, or to hold things together	• Robotic arm that used a worm gear	• Simple machines in Technology/ Engineering Section, Grades 3-5

[2] Table was developed through collaboration between members of the Tufts University Robotics Academy.

Energy transformation	When a certain form of energy changes into a different form	• All activities and projects using motors to transform electrical energy into mechanical energy	• Forms of Energy section of Physical Sciences, Grades 3-5
Friction	The force that creates resistance when two surfaces in contact move relative to one another	• Conveyor belts used to carry things up at an angle • All activities involving movement on a surface	• Motion of Objects section of Physical Sciences, Grades 6-8 • Identify and explain friction in Technology/ Engineering section, Grades 6-8
Four bar linkage	A structure that has two fixed point and two joints that connect the bars that attach the fixed points and that are only able to move in certain, predictable ways	• Amusement park with the surfing ride	
Programming	A way of using code to give instructions to a system so that it carries out operations in the manner and order in which you tell it	• Every project and activity that had been programmed	• Using symbols to communicate a message in Technology/ Engineering section, Grades 6-8
Robotic autonomy vs. remotely operated	The difference between an object that can operate itself by either reading programmed instructions or by organizing input that it collects and an object that requires input from a source other than itself in order to operate	• Every project and activity that had been programmed	• Using symbols to communicate a message in Technology/ Engineering section, Grades 6-8
Structural analysis	The process of assessing the structure of an object and developing structural changes that would make the object more efficient	• Every project and activity involving building	• Engineering Design Process of Technology/ Engineering section, Grades PreK-10

Tension	A force that tends to stretch or elongate an object	• Every project using conveyor belts	

Figure 14 *Amusement park project*

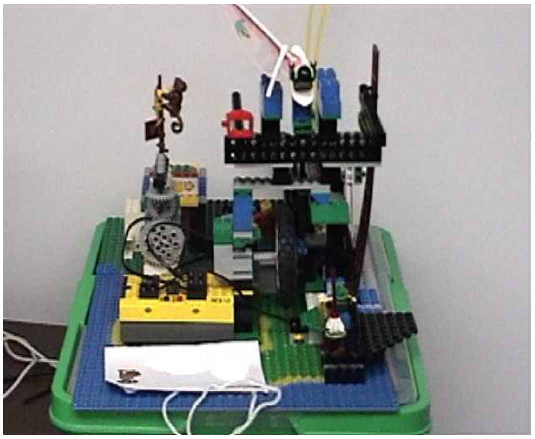


Figure 15 *Car with gears project*

Another important, although unfortunate, aspect of technology was that it was often malfunctioning and too difficult for someone with an average knowledge of technology to fix. We ran into this problem quite frequently during the first several weeks. We were using laptops that were continually rejecting commands and not running the software properly. It made the workshop more frustrating for the boys because it was hard enough for them if everything was functioning correctly; they didn't need difficulties with the technology on top of all of that. In fact, one boy reported in his paper and pencil journal that he could never find a computer to use. During the later weeks of the workshop, this wasn't such a problem because we were more efficient at fixing the computers when they stopped working and we were using better, more reliable computers.

One significant advantage of a technology like LEGO Mindstorms and ROBOLAB was that it allowed children of all abilities and with many different interests to find their niches. Some boys excelled at the building component of the project, while others did at the programming aspect. Still others, who were more musically inclined, were able to exercise their abilities in that arena. According to the principles of constructionism, this robotic technology allowed children to engage in personally relevant discovery, as there were so many ways for them to find something about the technology that appealed to them. This resulted in a more meaningful understanding of the subject matter.

During the presentation day, the parents offered us a lot information about how their sons felt about the workshop. As parents are often the best indicators of their children's attitudes, perhaps we should have also given the parents a questionnaire that elicited responses about how they thought their children felt about the workshop and about the technology. The parents voiced very positive feedback about the workshop after the boys finished their project presentations. Many parents explained that their sons were always looking forward to each week's session. One parent said that his son had asked him to pick him up on the late end of the session since he had arrived a few minutes late and wanted as much time as possible. Most parents wanted information about similar programs that the CEEO would be offering. The only negative report from a parent was that her son didn't like that there were a lot of strange people there, which must have been the engineer who was hired to help and the Child Development students from the Robotics in Education course who were there to observe, document, and help out.

Also during the presentation day, the benefits of having used constructionist principles were apparent. The boys were eager to describe their projects that they had chosen out of personal interest. They were able to explain the science and engineering principles involved in their projects, as they were forced to tackle them in order to accomplish what they had set out to accomplish. They were motivated to progress because they were working at hands-on things that interested them, while also using technology that was motivating in itself. Thus, they were learning by constructionist principles, and their enthusiasm for and understanding of the technical aspects involved in their projects, which were apparent at the presentation day, proved that the robotic technology and the methods of utilizing it as an educational tool in the after school setting were effective.

During the presentations, one boy described the issues he experienced with tension when he talked about his conveyor belt. He said, **"I couldn't get it tight enough, so it just wouldn't run."** Another boy described, **"It has two motors down here because this part is so heavy that one motor wouldn't make it lift up."** He went on to describe that the small motor he used to make the heavy part lighter was attached to a worm gear. He explained his system of counter-balance, a concept related to the lever concept, and said, **"This is so heavy when it goes down that it actually brings the whole thing with it."** A third boy talked about some changes he had to make to his project. He said, **"I had to keep on adding speed. At first I only had one of these [points to a motor]. I put down two because this wasn't strong enough to turn all the gears."**

A change in attitude

Based on the questionnaires, the boys viewed general technology and typing as easier after eight weeks of the workshop than they had viewed it at the start of the workshop (see appendix D). Although we only used one type of technology in the workshop, the boys reported other types of technology as easier. By acquiring experience and developing comfort with a technology through practice with it, the boys felt that other things related to technology may be easier. They also reported at the end of eight weeks of working with robotics that they viewed building a robot as harder to do than they had originally reported viewing it. This could be a reflection upon their difficulties in carrying out the construction of their lofty ideas for their robotic projects. It may also be due to the discovery of more problems in building with LEGOs than they had expected since most of them had experience with LEGOs. Securing the LEGOs to the RCX and accounting for the motion of the object that may have jostled the LEGOs were aspects that they weren't accustomed to considering.

The group was self-selected and composed of only boys. Therefore, this is not to say that a coed group or a group of all girls would operate in the same way or finish with similar experiences. Particular recruitment strategies should be employed to build a more diverse group, the results from which could be more accurately generalized to larger groups. More research is needed to assess groups with more variation.

Conclusions

This section is organized to sum up the success of ROBOLAB as an educational tool. It also provides closing remarks about the project at the undergraduate level and as a personal project.

Success in an after school setting

The after school setting was ideal for holding and testing the efficacy of this robotics workshop. We were not required to do any particular curriculum or to show proof that the children could perform well on tests about the subject matter. We had the materials available to us, as well as a number of assistants in most cases. The assistants in the workshop had experience with the technology and were able to guide the children through their activities. We weren't under any time constraints, and we could pace the workshop according to the boys' progress and expectations.

As our educational system stands, it would be difficult to implement this type of robotic technology into the classroom setting. Teachers at schools are on a tight schedule, and many are required to teach about specific areas, in the attempt to get their students to perform well on examinations. It is also expensive and time-consuming to bring this type of technology to schools. Teachers who are not familiar with the technology must be trained how to use it as an educational tool. However, we find that a basic knowledge of this robotic technology is sufficient in leading the group, as they are able to figure out and answer many of their own questions.

This technology has valuable benefits that would enhance the educational experience. It can engage children in hands-on interactions with their tools and it can promote a deep understanding of the principles involved in their work. It engages students in the engineering design process, which is an area that the Massachusetts Curriculum Frameworks requires for schools to cover in the subjects of Science and Engineering/Technology (Massachusetts Curriculum Frameworks). For example, each boy practiced structural analysis in assessing and improving the effectiveness of his project's physical structure. Structural analysis is one portion of the engineering design process.

Although the after school setting fosters a positive environment for the implementation of robotic technology, it also has limitations. The workshop costs money and is located away from a child's school, so a family's inability to pay for it or to provide transportation to the site may exclude a child from participation. In addition, a group that is self-selected, like the group that we worked with, is not representative of the general population of children. Our group drew only those children who have an interest in LEGOs or robotics. Incidentally, the group turned out to be composed of all males. Therefore, these participants are not able to share in their experimentation of robotic technology with children who have other areas of interest or with females, while both of these groups may still be interested in and learn from robotics and have a lot to offer to the other children. Implementing this type of technology into classrooms would automatically include every type of child.

Success with pre-service teachers

We found that child development students enjoyed the opportunity to become familiar with an educational technology, as many of them hadn't previously been exposed to such a thing. However, the students who were interested in educational technology were the ones who took the course, so they're more likely to appreciate the exposure. They also found their experiences in the after school workshop particularly valuable, as their hands-on participation was a form of constructionist learning in which they could use their knowledge of ROBOLAB and practice teaching with the theories that they were learning in class. They reported that they would be more likely to use such technology in a classroom after having taken the course. For more information, refer to the project website at www.ase.tufts.edu/devtech/roboticsineducation/HOME.HTM, and see Diana DeLuca's thesis (DeLuca, 2003).

The Robotics Academy, undergraduate education, and personal reflection

As members of the Robotics Academy, we were practicing constructionist learning as well. Working in a group with varied backgrounds and interests exposed us and gave us practice with the type of collaboration that we will have to use in our futures as college graduates. We all took on aspects of the project that were personally meaningful, thus motivating us and making the experience more relevant and valuable to our own experiences. We were also all exposed to other disciplines and had to learn about other disciplines in order to understand the bigger picture of the project. The experience helped me to become more comfortable in my interactions with people of differing backgrounds and expertise. My involvement in the group improved my undergraduate educational experience by expecting me to pursue hands-on learning based on my interests.

My personal experience in writing this thesis has been tremendous. I became interested mostly because I wanted to take part in the thesis process. I chose to work on this project because it seemed very fun and exciting and because it was already somewhat structured, since I knew that I would have difficulties in structuring a thesis project for myself. However, the more I became involved in it, the more I realized that it wasn't really structured at all. In fact, Diana and I had so much freedom with the project that I think it was more difficult. At so many points in the process, I felt completely overwhelmed by all the decisions that were up to us. However, it enabled us to guide our own work, and we ended up creating a project that was our own. This was good for me, as I could benefit from having to make big decisions and then carrying them out. In terms of working with the large Robotics Academy group, it was very intimidating at first. For a child development major with little training in science and technology, there's nothing like sitting in a Fluid Turbulence Lab with a bunch of men who are all quite experienced in various fields of engineering.

However, once we were able to relate on a more personal level, the interactions were generally comfortable and easy. There were many times in which I looked to their expertise for guidance about how to proceed with the robotics workshop. I will take away from this project much more than just an understanding about how ROBOLAB is a great learning tool in an after school setting (although I am 100% convinced of that). I can use others for advice about areas that relate to their fields, I have taught peers, I learned how to use IMovie, and I have done so much more that will contribute to my educational and life experiences. By participating in such a project, I have learned about ROBOLAB, teaching, learning, working in groups, all according to the theoretical framework of constructionism.

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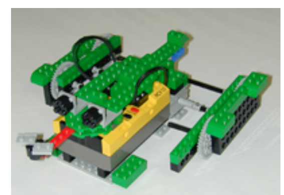
Appendices

A. After School Robotics Workshop flier

After School LEGO workshop at Tufts

WHAT: Tufts' Center for Engineering Educational Outreach is offering a Tuesday afternoon LEGO after school workshop. Over the course of the program, students will learn basic principles of mechanics and robotics through the manipulation of LEGO structures that they will build in small groups of two or three. They will use the ROBOLAB software to program their creations to move and operate independently. Concepts related to friction, pressure, and programming will be explored, as well as those that naturally arise during the sessions. Although basic mechanics and LEGOs are the focus of the program, we also expect it to be a fun and creative environment in which students will be encouraged to pursue their own interests in working with the technology. No previous experience is required.



WHEN: Jan 21,28; Feb 4, 11,25;Mar 4,11, 25; Apr 1,8,15
(The after school workshop does not meet during public school winter break and Tufts spring break)

TIME: 3:15-5:15
(students may arrive between 2:30 and 3:15 and MUST be picked up by 6:00pm)

WHERE: The Center for Engineering Educational Outreach on Tufts' Medford Campus (474 Boston Ave, Curtis Hall, Medford)

WHO: The workshop is open to students in grades 4-7.

COST: The cost for is $200.

The tuition includes use of RCX, LEGO bricks, computers, educational guidance, and a snack.
Tuition does not include LEGOs to take home.

Need Based Scholarships Applications Available On Request

If you have any questions, please contact Elissa Milto (e_milto@yahoo.com) or Merredith Portsmore (Merredith.Portsmore@tufts.edu) at 617/627-5888.

Detach the form below and mail along with payment to:

Center for Engineering Educational Outreach
LEGO Afterschool Workshop
200 College Avenue,105 Anderson Hall
Tufts University
Medford, MA 02155

Student's Name ______________________________________
Grade __________ Sex M/F__________
Street Address ____
City ____________________________ State _______ Zip Code _______________
Name of parent or guardian ____
Home Phone (__________) ______________-________________________
Day Phone (__________) _____________-________________________
Parent e-mail

B. Consent form

January 21, 2003

Dear Parents:

Our names are Diana DeLuca and Laura Hacker, and we are students at Tufts University working on our senior honors theses in the department of Child Development. We are conducting an after-school workshop that uses a type of robotic educational technology, called ROBOLAB. Children are invited to come and participate in building LEGO constructions which they will program using the ROBOLAB software. In terms of our theses, the purpose of the workshop is to understand more about teaching science and engineering to children, using elements of technology.

We are writing this letter to ask your permission for your child to participate in this after-school workshop. They will be working with a team of undergraduate students who will be supervised by members of the Tufts Center for Engineering Educational Outreach. The undergraduates will support the children as they explore the technology and science concepts. **The workshop will be held from 3:15 to 5:15 on the following dates, January 21st and 28th, February 4th, 11th, and 25th, March 4th, 11th, and 25th, and April 1st, 8th, and 15th at the Tufts Center for Engineering Educational Outreach**.

During the workshop we will distribute questionnaires to your children that ask about basic demographic information, children's prior experiences using technology in school and out of school and their feelings about using it. The questions will also target their opinions about technology as a teaching tool, in terms of how useful it has been for them and how useful it may be for others. As a means of evaluation, we plan to videotape the sessions. The videotapes will only be viewed by the investigators and will not be used for other purposes. We also plan on taking still photographs during the sessions. With your consent, these photographs may be posted on the internet without using names, along with the description of our results.

If you have any questions, please do not hesitate to contact Diana DeLuca at 781-367-3381 or via e-mail at diana.deluca@tufts.edu or laura.hacker@tufts.edu.

Sincerely,

Diana DeLuca

Laura Hacker

_______I **do** give permission for my child to participate in the workshop.

_______I **do not** give permission for my child to participate in the workshop.

Parent's signature/date ____

Parent's name ____

Child's name ____

I give my consent to the principle investigators to videotape my child in the workshop setting. I understand that these videotapes will not be viewed by anyone with the exception of the investigators. I also allow the investigators to take photographs of my child during the workshop, understanding that these photographs may be used on the internet without name identification as a supplement to the results of the project.

____

Parent's Signature/ Date

____

Name of Child

C. Questionnaires

Pre-Questionnaire

Afterschool LEGO and Robotics Workshop

Name:
Age:
Grade in school:

Directions: For numbers 1 and 2, write a number in each blank space.

1. In my classroom at school, there are ____ computers.

2. At my house, there are ____ computers.

Directions: For numbers 3-5, circle the one for each question that is the best answer for YOU.

3. I use the computer(s) at my school:

never   less than once a month   once a month   2-4 times a month

once a week   2-4 times a week   about once a day or more

4. When I use the computer(s) at school, my teacher usually:

gives me lots of directions   gives me some directions

does not give me directions

5. I use the computer(s) at my house:

never   less than once a month   once a month   2-4 times a month

once a week   2-4 times a week   about once a day or more

Directions: For numbers 6-13, put a check in the boxes next to <u>*all*</u> *the answers that are true for YOU (you may check more than one box for each question).*

6. I have learned to <u>type</u> on the computer:

☐at school   ☐at home   ☐at another place besides home and school

☐I have never learned to type on the computer

7. I have learned to use the <u>internet</u>:

☐at school ☐at home ☐at another place besides home and school

☐I have never learned to use the internet

8. I have learned to use e-mail:

☐at school ☐at home ☐at another place besides home and school

☐I have never learned to use e-mail

9. I have learned to play computer games:

☐at school ☐at home ☐at another place besides home and school

☐I have never learned to play computer games

10. I have learned to make graphs or charts on the computer:

☐at school ☐at home ☐at another place besides home and school

☐I have never learned to make graphs or charts on the computer

11. I have learned to make websites:

☐at school ☐at home ☐at another place besides home and school

☐I have never learned to make websites

12. I have used a robot:

☐at school ☐at home ☐at another place besides home and school

☐I have never used a robot

13. I have built a robot:

☐at school ☐at home ☐at another place besides home and school

☐I have never built a robot

Directions: For numbers 14-22, circle the one for each question that is the best answer for YOU.

14. I think most technology is:

really easy sort of easy not easy or hard

sort of hard really hard I've never used technology

15. I think <u>typing</u> on the computer is:

really easy sort of easy not easy or hard

sort of hard really hard I've never typed on the computer

16. I think the <u>internet</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I've never used the internet

17. I think <u>e-mail</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I've never used e-mail

18. I think <u>computer games</u> are:

really easy sort of easy not easy or hard

sort of hard really hard I've never played computer games

19. I think making <u>graphs or charts</u> on the computer is:

really easy sort of easy not easy or hard

sort of hard really hard I've never made graphs or charts on the computer

20. I think making <u>websites</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I've never made websites

21. I think <u>using a robot</u> is:

really easy sort of easy not easy or hard sort of hard really hard I've never used a robot

22. I think <u>building a robot</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I've never built a robot

23. In this afterschool LEGO and robotics workshop, I want to learn or become better at:

____

____

24. My favorite snack is:

____

Now let's have fun!

Post-Questionnaire

After school LEGO and Robotics Workshop

Name:

Directions: For numbers 1-10, circle the <u>one</u> for each question that is the best answer for YOU.

1. I think most <u>technology</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I've never used technology

2. I think <u>typing</u> on the computer is:

really easy sort of easy not easy or hard

sort of hard really hard I've never typed on the computer

3. I think the <u>internet</u> is:

really easy sort of easy not easy or hard

sort of hard really hard I’ve never used the internet

4. I think e-mail is:

really easy sort of easy not easy or hard

sort of hard really hard I’ve never used e-mail

5. I think computer games are:

really easy sort of easy not easy or hard

sort of hard really hard I’ve never played computer games

6. I think making graphs or charts on the computer is:

really easy sort of easy not easy or hard

sort of hard really hard I’ve never made graphs or charts on the computer

7. I think making websites is:

really easy sort of easy not easy or hard

sort of hard really hard I’ve never made websites

8. I think using a robot is:

really easy sort of easy not easy or hard

sort of hard really hard

9. I think building a robot is:

really easy sort of easy not easy or hard

sort of hard really hard

10. I think programming a robot is:

really easy sort of easy not easy or hard

sort of hard really hard

11. In this after school LEGO and robotics workshop, I have learned or become better at:

1.____

2.____

3.____

12. My favorite part of the workshop is:

____

____

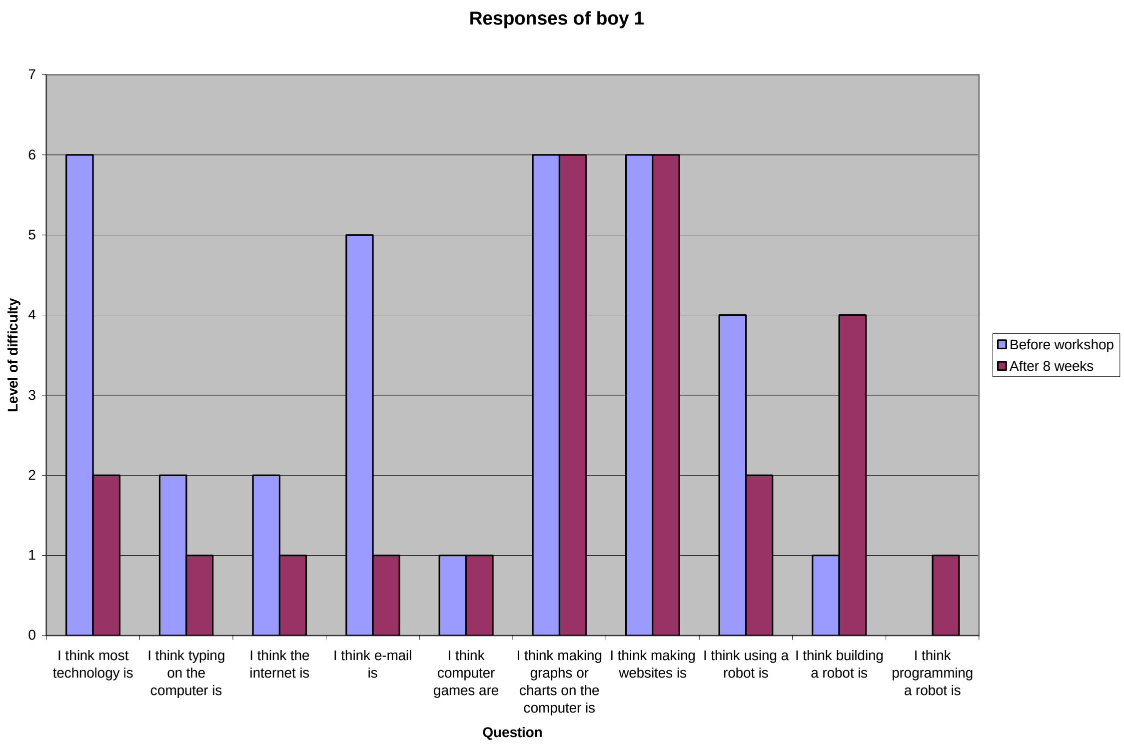
13. My least favorite part of the workshop is:

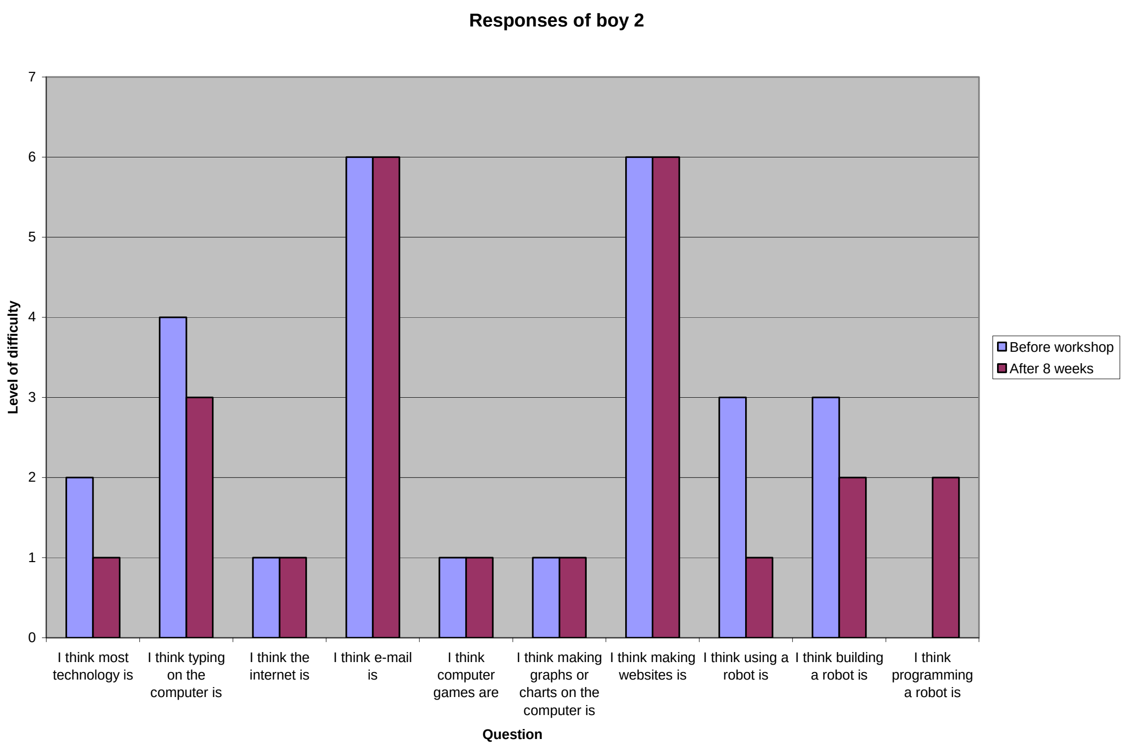
____

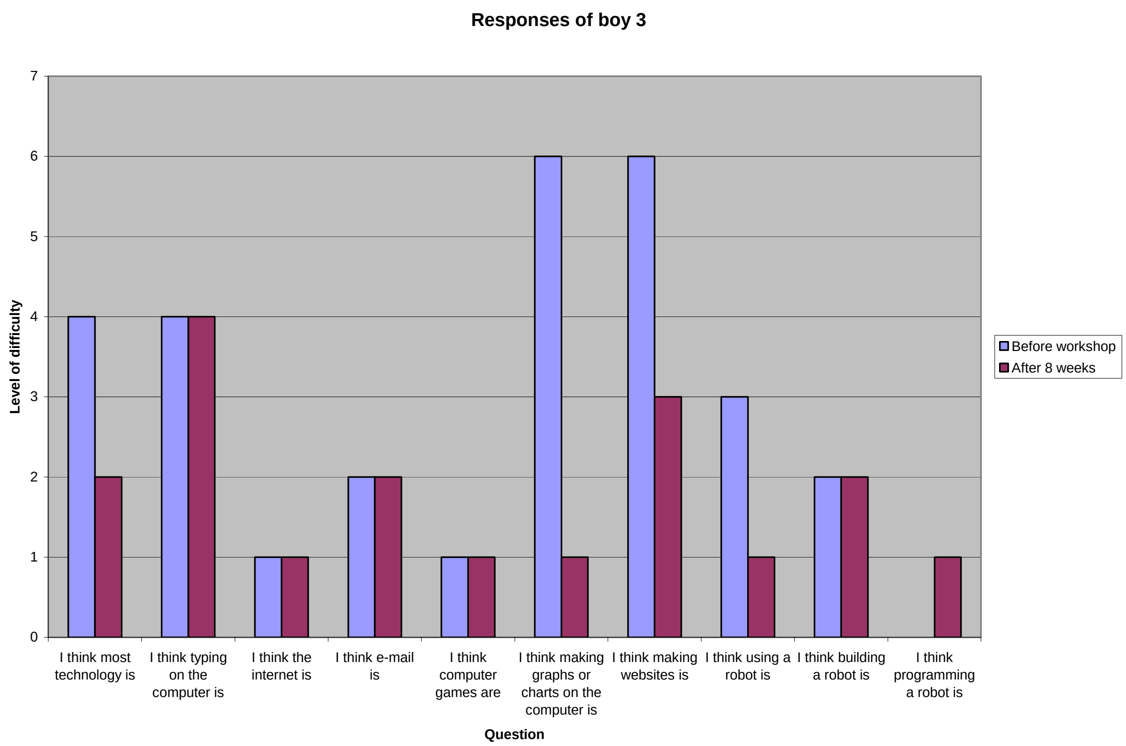
____

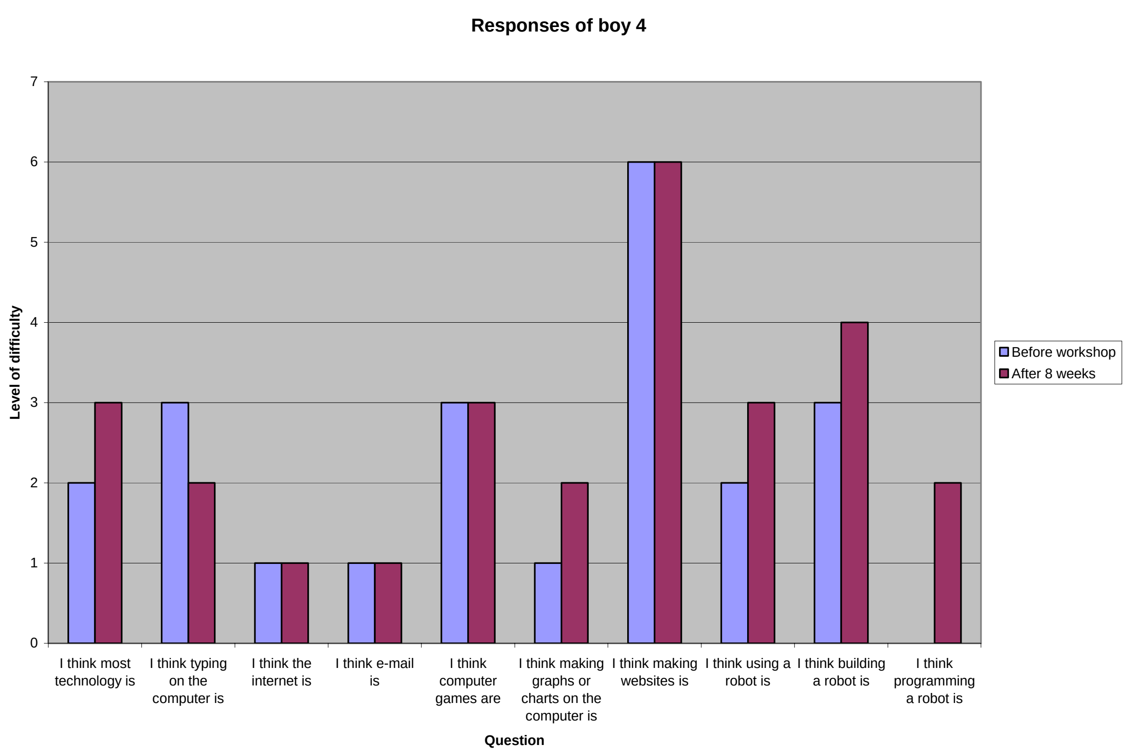
Thank you!

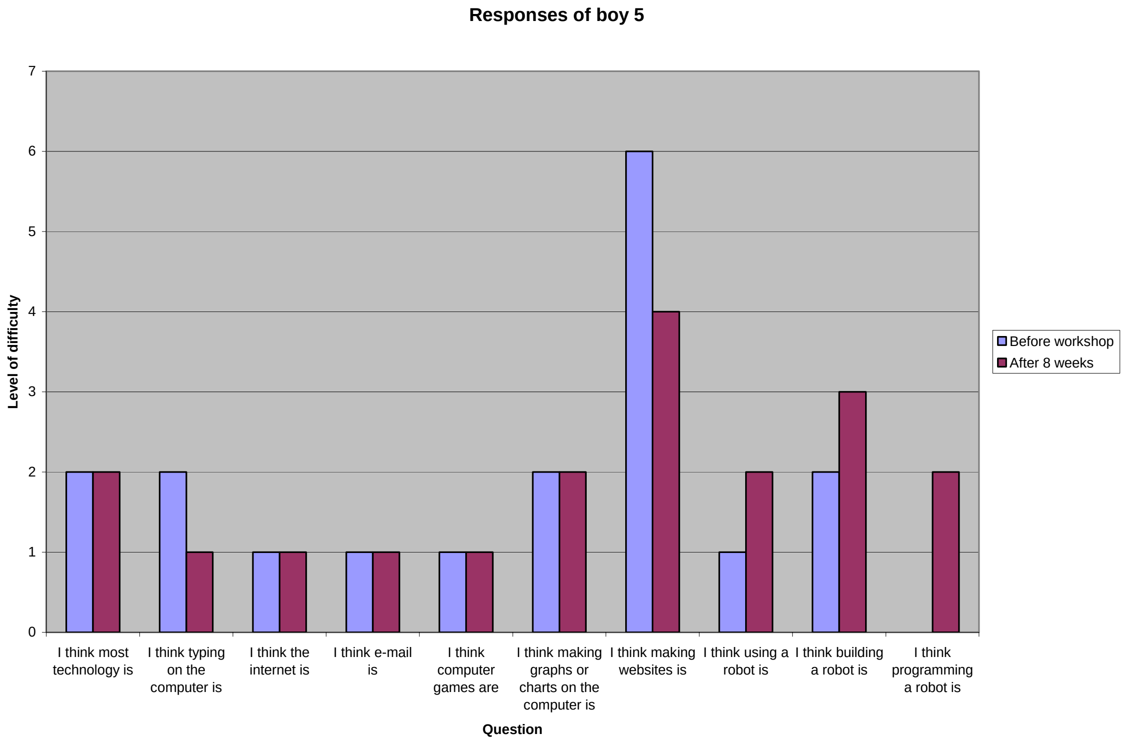
D. Questionnaire responses

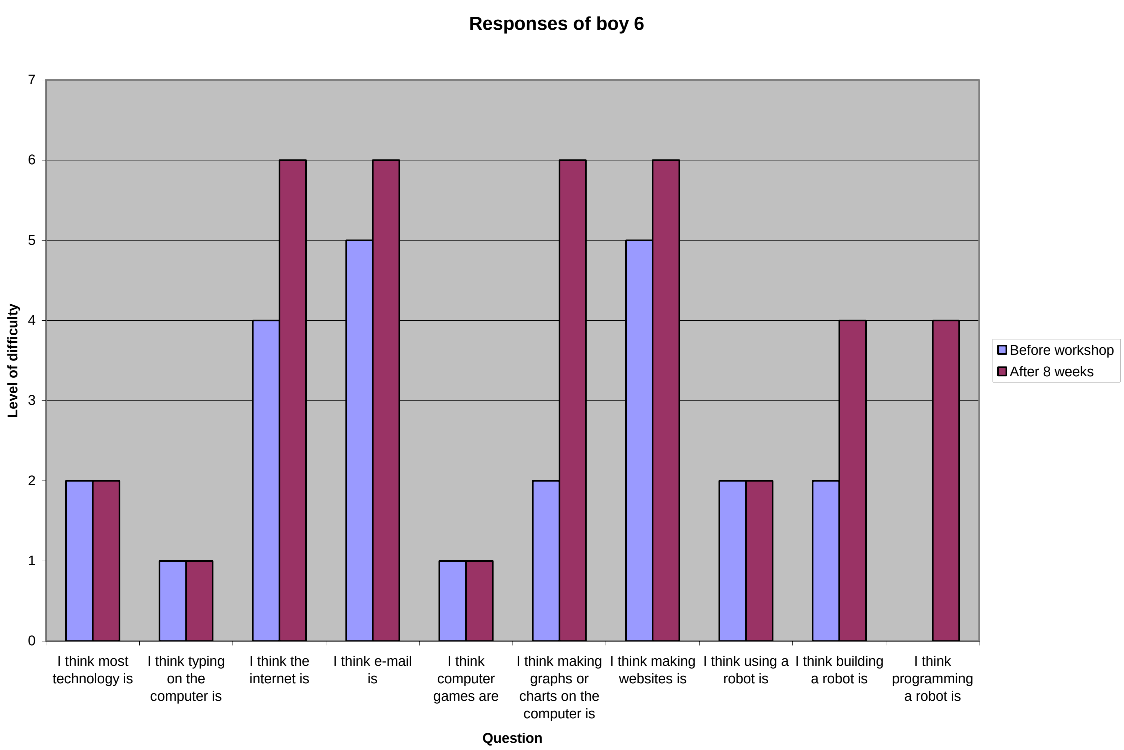





Responses of boy 3
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
I think programming a robot is
Question
Before workshop
After 8 weeks


Responses of boy 4
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
I think programming a robot is
Question
Before workshop
After 8 weeks


Responses of boy 5
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
I think programming a robot is
Question
Before workshop
After 8 weeks


Responses of boy 6
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
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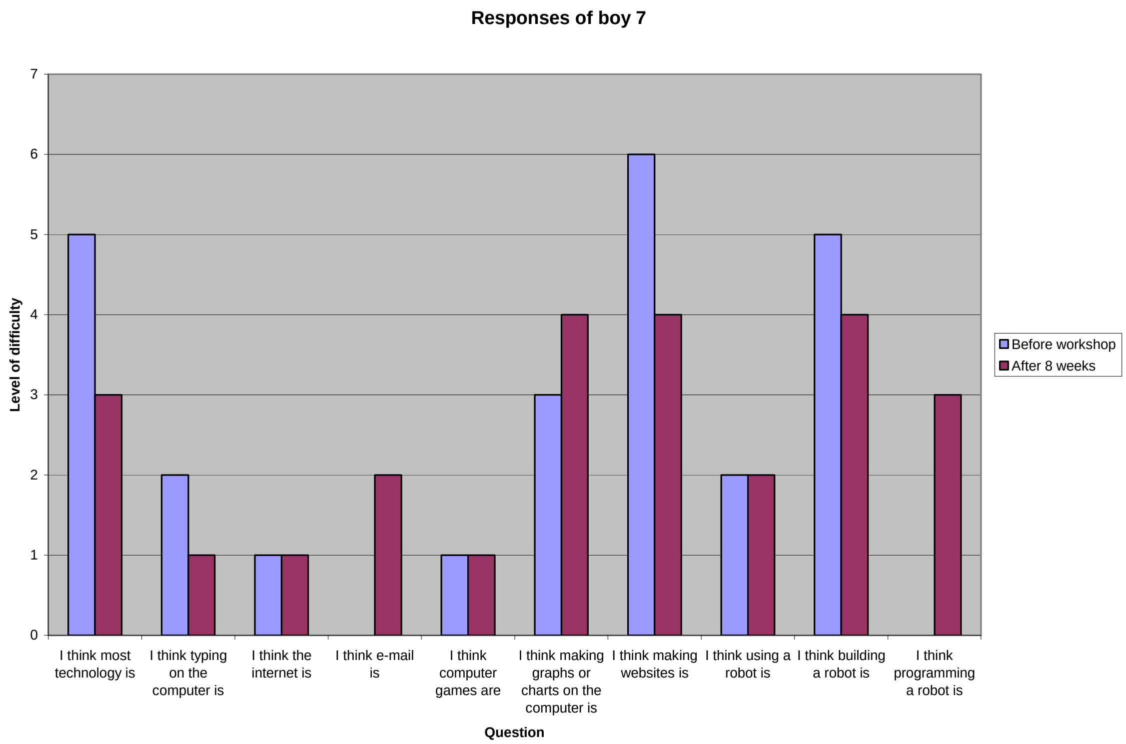
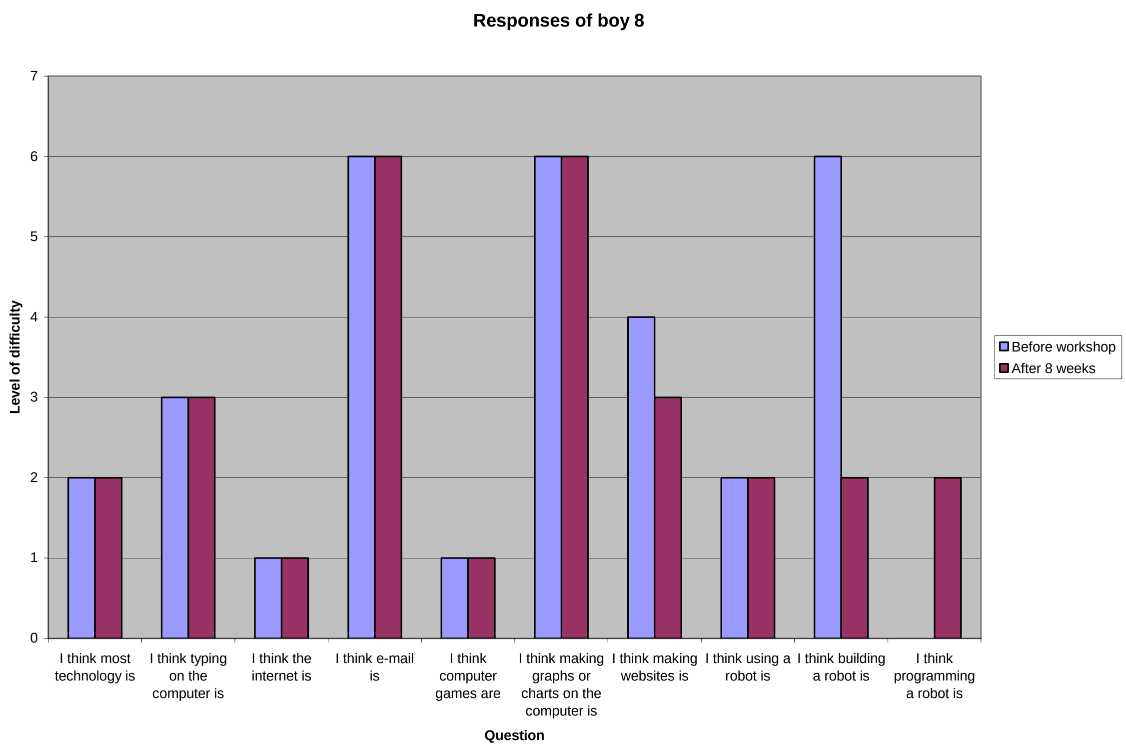
Question
Before workshop
After 8 weeks


Responses of boy 7
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
I think programming a robot is
Question
Before workshop
After 8 weeks


Responses of boy 8
Level of difficulty
7
6
5
4
3
2
1
0
I think most technology is
I think typing on the computer is
I think the internet is
I think e-mail is
I think computer games are
I think making graphs or charts on the computer is
I think making websites is
I think using a robot is
I think building a robot is
I think programming a robot is
Question
Before workshop
After 8 weeks