

# ROBOLAB

Intuitive robotic programming software  
to support lifelong learning

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## Introduction

One of the LEGO company's latest products is the RCX, an autonomous microcomputer embedded in a LEGO brick that can be programmed to serve as the "brain" of any LEGO construction. With the ability of the RCX to provide power to lights or motors and gather information with sensors, children and adults can easily develop creations that move, think, and react.



Figure 1. The RCX can store up to five different programs. Ports 1, 2, and 3 take input from sensors, while Ports A, B, and C supply power to motors or lights. (The RCX is approximately 2.5 inches by 3.75 inches.)

LEGO rolled out two different packages, one for the retail market and one for the education market, in fall 1998 to accompany the RCX. The retail package, titled MINDSTORMS, is found in toy stores and aimed at children 12 and older. The educational package for the RCX is called the ROBOLAB system, and it consists of a set of bricks and software created specifically for schools that keeps in mind the needs of teachers and the logistics of a classroom.

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To meet the requirements of the educational community, cross-platform software was needed that could be used by students with a wide range of ages and abilities. These needs were answered through the formation of a partnership between LEGO DACTA (the division of LEGO that distributes educational materials), Tufts University's College of Engineering, and National Instruments, makers of LabVIEW programming software. From this alliance came software, also titled ROBOLAB, for the PC and the Mac OS that has multiple levels of programming capabilities. Students from ages 5 to 25 can use ROBOLAB to create very simple or amazingly complex programs for their RCX-based creations.

LEGO elements and ROBOLAB are powerful tools for educators at all levels. These tools allow students to learn by creating and testing their ideas. Vested in a creation that is their own, students are motivated to understand what principles of science are demonstrated and how they can use their knowledge to improve or alter a design. Teachers have the opportunity to see that their students actually demonstrate what they've learned. ROBOLAB also provides an opportunity for students who are more hands-on or visual to succeed. Problem-solving and thinking skills become implicit lessons in this dynamic educational environment.



Figure 2. A vehicle made using the RCX.

Combining LEGO materials, computers, programming, and education goes back at Tufts further than the advent of the RCX and its software. More than four years ago, a grant was awarded to Tufts' mechanical engineering professor Dr. Chris Rogers by NASA to develop a web-based aeronautics curriculum for K–12 teachers. Rogers sought to do this using LEGO DACTA materials, including the Control Lab interface box and the student edition of National Instruments' LabVIEW software (LVSE) (seen in Figure 3) to teach the principles of aeronautics, such as force, friction, lift, and drag. Content knowledge and hands-on training with the materials were given to teachers during intense two-week workshops held during summers. Teachers posted their progress and activities during the year via bulletin boards, personal web pages, and e-mail. Through this process, Rogers and his group were able to better understand the needs and abilities of teachers and students, as well as the logistics of classrooms across the country.

Many of the teachers involved with this program have experienced great success with LVSE, but the learning curve has been high. Programming in LVSE is easy if you have some knowledge of programming concepts such as variables, control structures, and conditional statements. However, many teachers hadn't been exposed to programming before and it became an added skill they had to master. This delayed or prevented many teachers from attaining a comfort and confidence level that would allow them to use the software in their classroom. The teachers who have made use of it offered observations on how reading level and fine motor skills affected programming at different grade levels. They were also able to highlight and describe the number of different situations in which students learned to use the software (one computer in the classroom, multiple classroom computers, in the school computer lab). Moreover, the reality of the number of schools and classrooms that had a mix of both PC and Macintosh computers came to light as more teachers came to use it proficiently and teachers from around the globe downloaded it to use in their classrooms. All of this feedback was kept in mind when designing the RCX software.

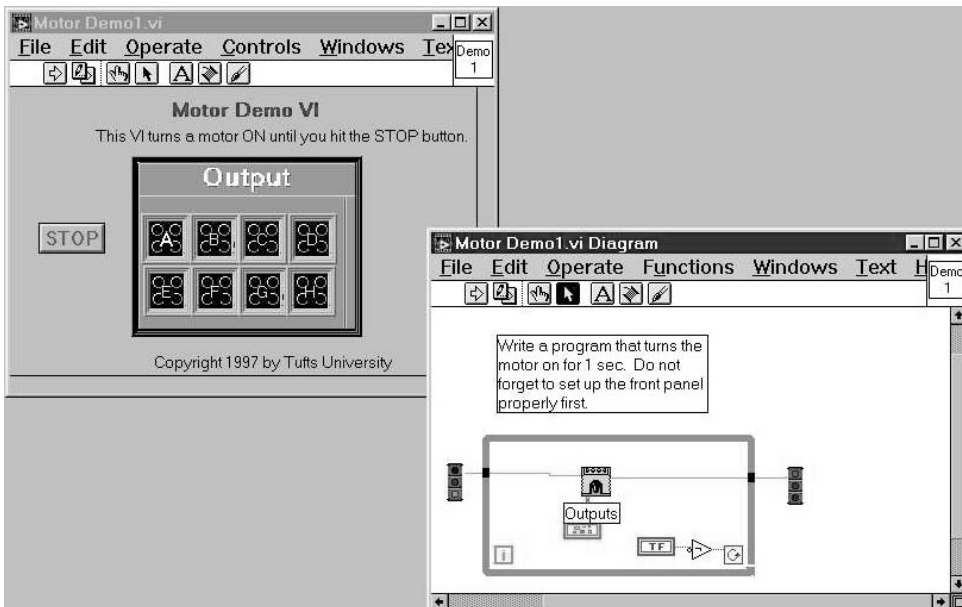


Figure 3. An old version of the LEGO programming using LabVIEW Student Edition. This version required users to be fairly comfortable with computers, managing multiple windows and programming structures (loops, variables, type definitions).

### How does ROBOLAB work?

Programs for the RCX are created on a computer using special software and then downloaded to the RCX using an infrared tower. The RCX can then run the program independent of the computer. On the educational side, ROBOLAB, which is powered by National Instruments' LabVIEW, is the software that is used on the computer to create programs for the RCX. LabVIEW is an industry-standard graphical programming language used by engineers and programmers in major companies and organizations, including Pepsi, Boeing, and NASA. LabVIEW's graphical interface allows users to program more quickly and easily using images and icons rather than typing in lines of code. Hence, with ROBOLAB, students as young as kindergartners, who aren't proficient at reading, can create programs by selecting recognizable images. Having LabVIEW power ROBOLAB allows for a high ceiling of programming capabilities, making it useful in high school and college situations.

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The programming capabilities are divided into two sections to accommodate the widespread needs of students. Pilot, the basic elementary section, and Inventor, the more advanced section, both use icons to represent commands or structures. In the Pilot section, the number and order of icon options is restricted to ensure the success of the user. This section requires very little reading, making it easy to use in the primary grades. It uses common images such as traffic lights, arrows, and watches to allow first-time users to construct elementary programs intuitively and quickly.

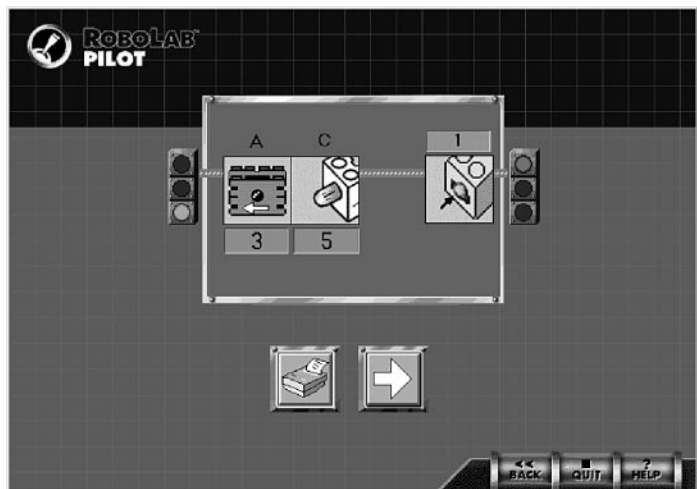


Figure 4. Pilot-Level 2—The green traffic light signals the start of the program. After the program is started, the motor on port A of the RCX is started going backward at power level 3, and the light on port C is started at power level 5. These two devices, which start simultaneously, remain on until the touch sensor on port 1 is pressed. The stop sign indicates the end of the program.

Programming in the Pilot section mainly entails selecting options from pull-down menus to form fairly simple programs of a linear nature. (See Figures 5 and 6.)

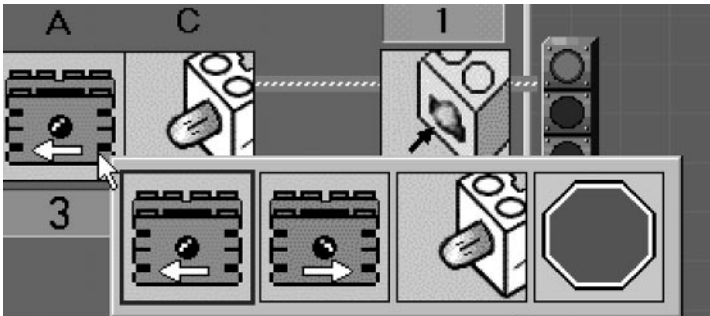


Figure 5. Output pull-down menu—Users can control the outputs on ports A, B, and C by selecting them from this menu. Motors can be run backward or forward, a light can be turned on, or nothing at all can be turned on (as indicated by selecting the stop sign).

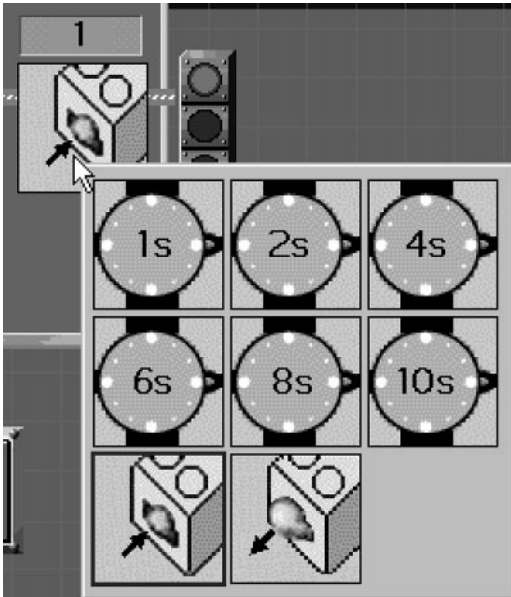


Figure 6. The “Wait For” menu. This menu allows users to choose how long their program waits before stopping the outputs. Users can select from time options (1 second, 2 seconds, and so on) or until a touch sensor (which operates like a button) is pressed or released.

There are four programming templates in the Pilot section that gradually build in difficulty, from the one-step programs (Figure 4) to the multistep programs (Figures 7 and 8) that provide more options for sensors and more customized parameters. The highest level of Pilot programming allows users to add steps as needed and customized statements. While a detailed manual accompanies the ROBOLAB software, the Pilot section allows first-time users to create working programs in just minutes and gradually progress to more complicated programming. Teachers have found that children can progress through the four levels in Pilot with very little instruction.

The Pilot section doesn't allow users to exploit the full potential of the RCX; however, it does provide a place where everyone can see the connection between programming and the actions performed by the RCX. Many elementary school teachers and children never move beyond this level, as it gives them all the power they need for programming many LEGO creations. Advanced programmers also often use this level to test their creations or programming ideas quickly and easily.

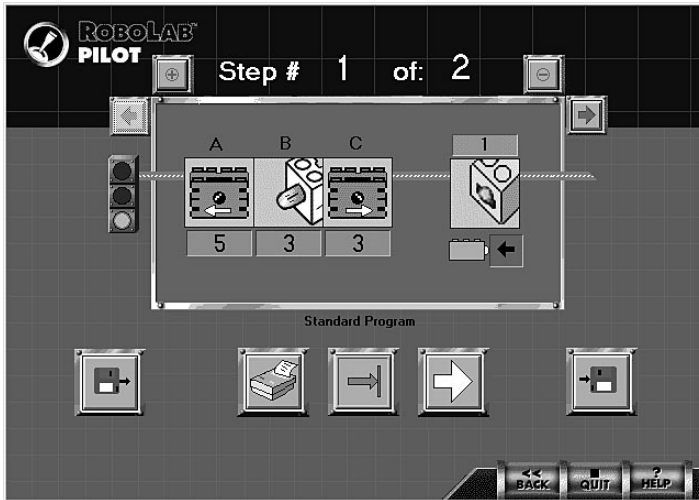


Figure 7. Pilot-Level 4—Step 1 of 2—This program turns the motor on port A on at power level 5 going backward, the light on port B on at power level 3, and the motor on port C on at power level 3 going forward. These three ports remain in this state until the touch sensor on port 1 is pressed. After this occurs, the program moves to Step 2, shown in Figure 8.

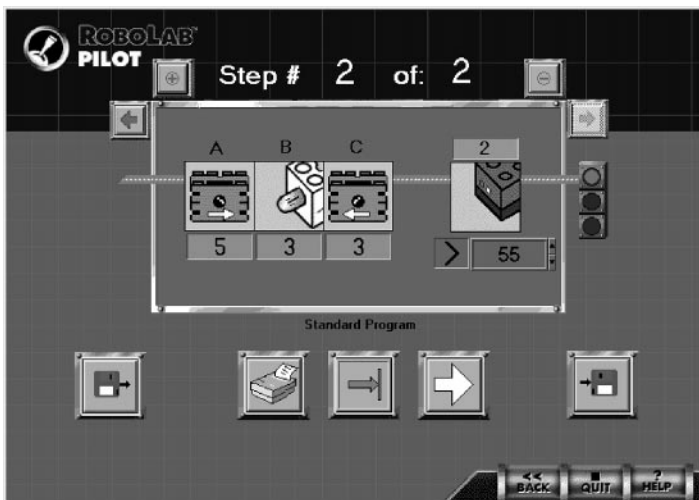


Figure 8. Pilot-Level 4—Step 2 of 2—This is the second step of the program. Here, port B remains the same but the motors on ports A and C switch direction. This state continues until the light sensor on port 2 detects a light value greater than 55. After this occurs, all motors and lights shut off and the program stops.

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To meet the needs of the middle and upper grade students as well as other ambitious programmers, the Inventor section offers a new level of flexibility and power coupled with a slightly different but still graphical interface. Similar to the Pilot section, there are four levels that gradually add complexity.

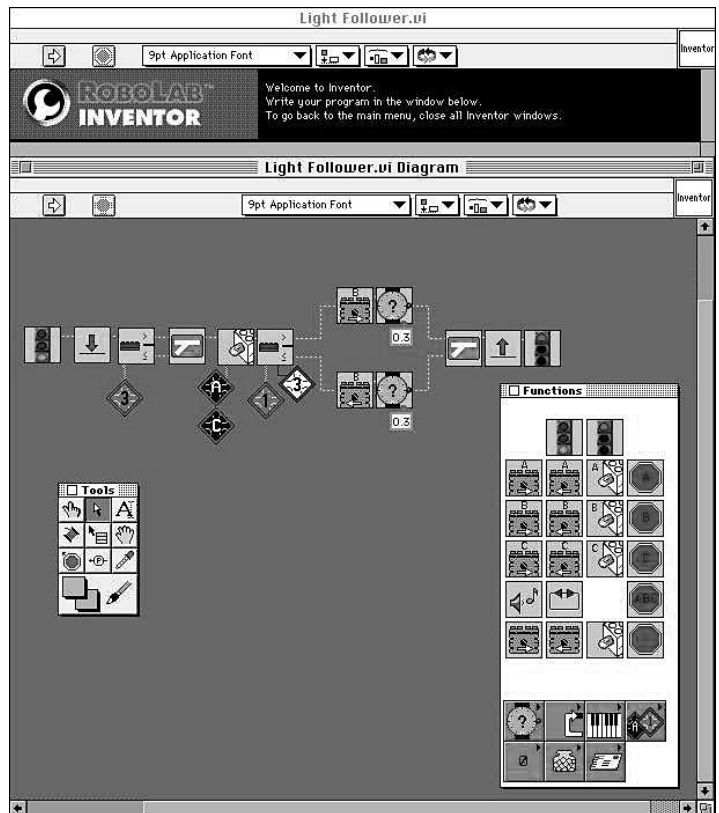


Figure 9. Inventor-Level 1—This program, similar to the Pilot level, is started and stopped by the traffic lights. Ports and power settings are changed by wiring diamond-shaped modifiers to icons. This particular program allows a car with a light sensor to follow a black line by turning the car based on the values detected by the sensor.

In the Inventor section, options are chosen from the functions palette and strung together to form a program. This gives programmers an unlimited amount of options as well as a higher level of responsibility in making sure they include the necessary elements. The Inventor section provides higher-level programming structures such as multitasking, loops, variables, conditional statements, and the ability to create subroutines. In this section, there is virtually no ceiling on the program sophistication. Inventor programmers

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have access to all capabilities of the RCX. Moving from the Pilot to the Inventor Level can be a bit of a jump, as users need to learn the logistics of selecting commands and connecting them to form a program.

#### ROBOLAB in action

The ROBOLAB software is often employed by teachers who want to use hands-on methods for teaching science and math concepts. Students ranging in age from 9 to 19 used the materials this past year in three classrooms. The success and enthusiasm of the students is equaled by the glowing satisfaction of the teachers, who have been able to incorporate this high-level technology easily into their classrooms.

#### Fourth grade

Terry Green at the Brooks-Smith School in Lincoln, Massachusetts, offered a before-school “fun” elective to give fourth-graders the opportunity to use ROBOLAB and LEGO elements. The early morning elective started with 8 children, but quickly grew to between 12 and 14 boys and girls showing up on a regular basis for 8 weeks. The children worked on vehicles as well as structures that utilized the RCX technology. They even started planning an ambitious monorail system. Green, who hadn't had any training on the product or software, found it was fairly easy to use, especially since the students picked it up quickly. “The great thing about ROBOLAB and the LEGOs is that you can have the ‘expert kid’ who can teach you and the other kids. . . I learn best from the kids,” she said.

Although the elective didn't have specific educational goals, Green felt the children garnered hands-on experience that would help them later in their science learning. A science teacher herself, Green also noted the flexibility of the system and the software in an educational setting. “The brick frees up the resources. . . It really requires only one computer. Moreover, the equipment can easily go to other classrooms and the software can expand with the kids through many grade levels,” she noted.

The students were excited and dedicated to the elective. A conflict that forced Green to cancel a morning session was met with moans and groans. When asked by others how they liked the elective course, students would exclaim “Oh, it's really cool!” Green told how the students were saddened when the eight weeks came to an end and how she personally enjoyed the experience. “You feel like you are on the cutting edge of technology. You can go anywhere you want with it [ROBOLAB and the RCX].”

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#### **Eighth grade**

At Shady Hill School in Cambridge, Massachusetts, Barbara Bratzel's "Physics by Design" course for the eighth grade uses LEGO bricks, ROBOLAB, and the RCX in lab work to teach basic principles of mechanics and electricity/magnetism. Students begin the year by building their own simple vehicles. They use those vehicles and the ROBOLAB programs they create to conduct experiments related to velocity and acceleration. Students are engaged in the process and excited. One student said, "It's great to be able to say, 'Well, I'm programming a car in science class.'"

As the year progresses, students build more complicated vehicles and study more advanced ideas, such as friction and how to incorporate sensors into their creations. Students have gone on to build cars that can follow a line, music boxes, and even balances that can weigh objects in grams.

Bratzel feels that the ROBOLAB software fits easily into the classroom environment. "ROBOLAB is designed in such a way that students can begin programming using Pilot with very little instruction from the teacher. As they gain experience, they can move to more advanced Pilot levels and then to Inventor. I give my students a series of projects to do, which require progressively more complicated programming."

She emphasized how the students teach themselves a lot of the programming and derive a great deal of pride from that process. Moreover, she feels that this software and materials actually help students learn. "One important need that ROBOLAB and LEGOs fill is the need kids have to tinker. Often in traditional science classes, children are doing experimentation by simply following directions carefully. Using ROBOLAB and LEGO, they are instead crafting their own solutions to problems and, inevitably, testing and modifying their ideas again and again. From such tinkering comes real understanding."

Bratzel's class this year was so eagerly anticipated by students that it had to be filled using a lottery system because of the vast number of children that signed up for it. There are tentative plans to hold two sections of the class next year to try and meet the demand.

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#### College level

Tufts University's College of Engineering has developed a series of courses for freshman engineering students to expose them to engineering and the design process. The goal of these courses is to motivate and inspire students for the science and math classes they will need to take. These courses are only worth half the course credit of a traditional course such as chemistry or math, and meet only once a week for 75 minutes. One of this year's options in the area of mechanical engineering was "Prototyping Home Robots," taught by ROBOLAB developer Dr. Chris Rogers. Equipped with the RCX, ROBOLAB, and LEGO bricks and sensors, teams of students competed in a series of robotics competitions. Challenges included building a robot that could follow a line, participate in laser tag, and navigate a maze to extinguish a flame.

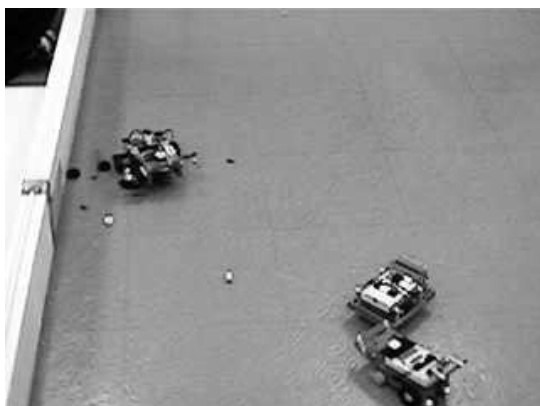


Figure 10. Three vehicles playing laser tag are a blur as they race and swerve to avoid being tagged.

While LEGO bricks may usually be the domain of younger children, students in the course were quick to highlight the benefits of the materials and the software in the college classroom situation. "LEGOs provided the perfect medium for learning engineering, including design and construction, with limited time and funds. Everything you need is given to you in a kit, and all the parts fit together perfectly, regardless of what you are building, and they are reusable afterward. The class involved a project a week. This would not have been possible if we had to build all the robots from scratch. Without LEGOs, a course like this would never have been offered to freshmen," stated freshman student David Friedman.

Michael Mattioli, a sophomore who has taken several programming courses, explained why the software put the class on an even playing field in terms of programming. "Learning a language like C or C++ can take years," he said, "while ROBOLAB is more intuitive."

The enthusiasm of the students was extremely high. Students often commented that they put more work into this half-credit class than they did their whole-credit classes. Rogers was also amazed by the students' interest. "They stay after class to work on their projects. I've never had students stay after class!" Students weren't just excited about the thrill of competition and getting to use toys, they were excited about learning. Friedman explained how the course impacted him, "This course reassured me that engineering was the right choice. It gave me a desire to study robotics further." Many of the students in the class emphasized how powerful their LEGO building experiences had been in teaching them how engineering works in terms of design and process, especially in the field of robotics. Marc Percher, another student in the class, described what he got out of the experience: "This course gave me a good understanding of what challenges can be found in creating a robot." Even Mattioli found it to be an educational experience, "...Perhaps the most important thing I learned from this class was that ideas that work on paper or in a computer don't always work in real life."

#### Future directions

ROBOLAB will continue to be used in both elementary and secondary education as well as higher education. NASA has funded several workshops in California, where more than 30 teachers have received training to use ROBOLAB and the RCX in the classroom. In the department of mechanical engineering at Tufts University, students in the junior-level experimental techniques course will be using ROBOLAB and the RCX. The course, which has been taught for the past three years using LEGO bricks and the student edition of the LabVIEW software, aims to teach all the elements of performing an experiment, analyzing the data acquired, and presenting the findings. The driving force behind this spring's class will be the design, construction, and automation of a TANG (the powdered orange drink) dispenser that allows the end user to specify concentration, temperature, and amount. A successful design requires that students monitor the powder-to-water ratio, control the temperature, construct a flow meter, and utilize a force meter.

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On the World Wide Web, visit the following sites:

<http://LDAPS.IVV.NASA.GOV>

<http://www.cceo.tufts.edu>

<http://www.lego.com/dacta/robolab>

<http://www.legomindstorms.com>

#### About the author

*Merredith Portsmouth (mportsmo@tufts.edu) received her undergraduate degrees at Tufts University in both mechanical engineering and English. She is currently working toward a master's degree in education at Tufts while serving as a research assistant and technical coordinator for the College of Engineering's Center for Engineering Educational Outreach (www.cceo.tufts.edu). Her research interests are focused on methods of improving in-service teacher training in the areas of science and technology through additional classroom support and asynchronous distance education.*