Bringing Engineering to Elementary School

Dr. Chris Rogers Merredith Portsmore

Tufts University

Abstract

Incorporating engineering in the elementary school curriculum provides students with ways of connecting, applying, and reinforcing knowledge in math, science, and design. To bring what is essentially a new discipline to K-12 education means developing and supporting new tools for the classroom, additional curriculum, teacher training, and support resources. Using LEGO materials and the ROBOLAB software as the toolset, Tufts University's Center For Engineering Educational Outreach has had significant success with our efforts to bring engineering into a number of schools and classrooms. Examining the classroom results these efforts have yielded highlights the problems and obstacles, a significant potential for expansion, as well as a number of effective practices and strategies.

Introduction

As our society becomes more dependent on technology, it becomes increasingly important that we make sure that students are comfortable with technology when they graduate from high school. [21] Making engineering a part of the K-12 experience helps give students experience with building and designing. It also serves to motivate their learning of the math and science concepts that make technology possible. At the Center For Engineering Educational Outreach (CEEO) at Tufts University, we have been working for over 15 years to integrate engineering into the K-12 experience; part of the work has helped establish the new engineering standard in K-12 education for the state of Massachusetts. Our goals are to excite students about engineering, math, and science, teach them these disciplines in a hands-on and practical way, and improve the engineering confidence of the next generation.

Engineering has the distinct advantage in the elementary school of being something students enjoy as it incorporates hands-on and creative work. Our efforts to bring engineering to the classroom are grounded in constructionist philosophy which puts forth that people learn better when they are working with materials that allow them to design and build artifacts that are meaningful to them. [2,3] Engineering supports this philosophy by effectively motivating students to learn math, science, reading, writing, communication, and design skills by giving students ownership of a project or process. Furthermore, because engineering problems require all of these skills, it is truly interdisciplinary in nature. In general, students learn to

1. identify and formulate a problem,
2. design a solution,
3. create and test a solution,
4. optimize and re-design, and
5. communicate and disseminate the solution.

Typically, steps 1, 4, and 5 are overlooked in a classroom environment when doing projects in other disciplines, yet these steps are often the difference between success and failure in the real world. Making the engineering design process part of K-12 education gives students an effective tool for approaching problems and creating solutions. Engineering has the secondary advantage that it appeals to both genders, a variety of learning styles, and multiple intelligences. Although engineering does appeal to many students, one must be careful in how to present the engineering challenge and how to teach the students to work productively together.

To effectively teach engineering, one must first develop a toolset for the students to use that allows them to build and design freely, easily, and with the greatest functionality. We have developed a number of toolsets, both cheap and expensive, with the goal of giving the teachers and students of all ages the hardware and software to build just about anything, while requiring them to learn math and science along the way. To do this and to really make a difference, we decided 5 years ago to team up with LEGO and National Instruments. LEGO brought extensive dissemination and support as well as the highly adaptable hardware component to the table. National Instruments brought an equally flexible software platform through LabVIEW that allowed us to push the ceiling of the toolset well beyond high school yet keep the entry level simple enough for the kindergarteners. The result of this collaboration was ROBOLAB, a highly successful set of hardware and software that allows students from 5 – 50 to learn engineering in a hands-on, creative, and exciting fashion. [7-9,22,23] We use these tools to motivate students to learn math, science, and engineering.

The LEGO hardware consists of the LEGO Mindstorms RCX and tower. The RCX (Figure 1) is a microprocessor in a LEGO brick capable of controlling motors and lights, reading sensors (ranging from light to heart-rate to compass heading), and reading time with 4 on-board timers. [2,3] The microprocessor can make decisions, run multiple tasks simultaneously, and even control other microprocessors – either in the same room or somewhere else over the Internet.

Figure 1: The RCX

LEGO sensors, actuators, and building blocks coupled with the RCX allow a user to quickly and easily build an engineering invention. For instance, 5 years ago it would have taken months to put together an animal that walks around a room avoiding walls. The electronics training and computer programming training required for such an undertaking limited the possible audience to high school and university students. With LEGOs and the RCX a 2nd grade student can make her own wall-avoiding turtle in just a few hours.

The ROBOLB software is powered by National Instrument's LabVIEW —a programming environment that was originally developed for university and industry research laboratories with the idea that software development time can be minimized by providing a graphical programming environment. The software has multiple levels of capabilities to allow for users as young as 3 years old to start programming. [23] The Pilot Level (Figure 2) allows users to program quickly and easily by changing a template. The Inventor Level (Figure 3) provides all the capabilities of the RCX and Labview by allowing users to create programs by stringing commands together. ROBOLAB has an additional section for collecting data with the RCX and analyzing that data (Figure 4). The software also provides users with the tools to create music, perform image and audio processing, and control RCXs and other LEGO hardware via the Internet. Because it is built on LabVIEW, users can take advantage of the complexities of the software and hence the upper level of ROBOLAB capabilities is only limited by the LEGO hardware.

The LEGO/ROBOLAB toolset is universal enough that kindergarten students and college students can build something completely different with the same materials. It is easy enough to use that the main classroom discussions can center on the physics of the problem or the design philosophy and not the tool usage. It is important that students do not get hung up with the tools and lose sight of the engineering or the science. There is a common misconception that technology equals computers and therefore students must learn how to use a computer. The computer (or RCX or other LEGO parts for that matter) is just a tool to help the student learn how to solve a problem. This paper is split into three main parts: the first part, Engineering in the classroom, is for the practitioner, demonstrating how the tools can be used to teach math, science, and engineering. The second and third parts, ROBOLAB Successes and Lessons Learned, look more at what has been successful and what we have learned along the way. Initial concepts of how students learn, how teachers and school systems change, and how to take something from an idea at a table to over 30,000 classrooms around the world are presented as well.

Engineering in the classroom

The first step in testing the toolset and its ability to allow students complete flexibility in what they create is in the classroom. In this section, we outline a number of different design challenges we use to teach math, science, reading, writing, and engineering. The curricula we present here is a small portion of the full curricula that can be found at the web site for the Center For Engineering Educational Outreach at Tufts (http://www.ceeo.tufts.edu) that has been developed over the past 5 years. [25] (Appendix A)

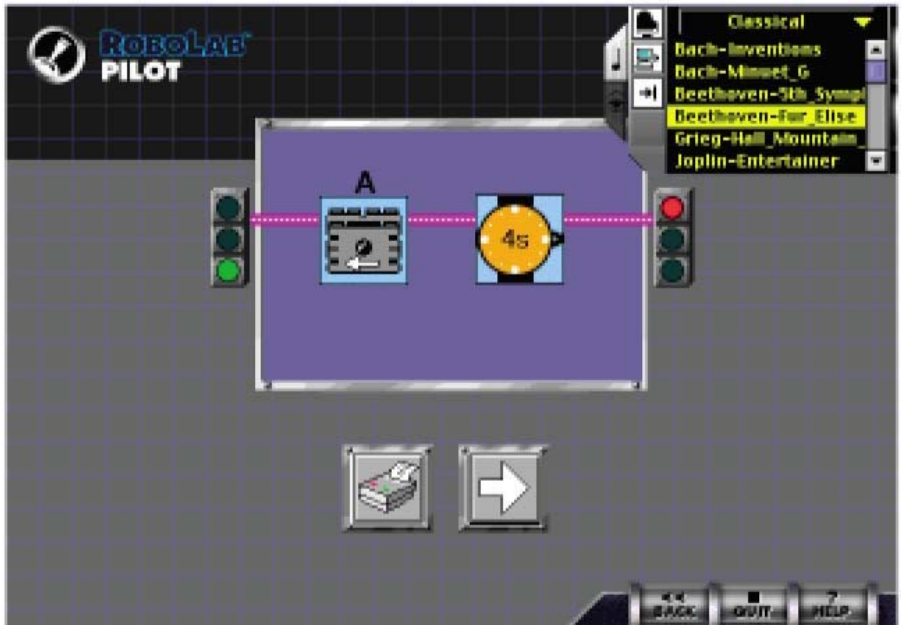

Figure 2: A pilot level program that turns on Motor A for 4 seconds while playing Beethoven's Fur Elise

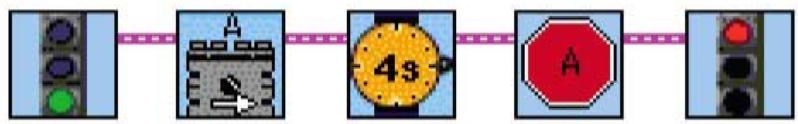

Figure 3: A basic Inventor program that turns on motor A, waits for 4 seconds, and turns off motor A.

Age Appropriateness

In general, we have found that elementary school students are capable of beginning to learn about important physics concepts (friction, forces, etc.), programming concepts (go to statements, wait statements, etc.), and math concepts (reading graphs, modeling, decimal numbers, etc.) much earlier than expected when presented in the context of engineering design projects. We have had kindergarten students arguing about frictional forces in their axles and third graders interpolating a calibration graph.

In general, table 1 shows the progression we use in the schools.

Every year we iterate the concepts of the previous year. The sequence is not exacting, many concepts could be presented earlier or later depending on student interest or ability. The key is to design a spiral-like curriculum that continually relies on what was learned the previous year so that the students see how their knowledge is building. [5] However, each year the concepts are revisited in new ways and integrated with different subjects to prevent boredom and burnout as well as demonstrate how concepts can be utilized in different areas. The overriding theme throughout the curriculum is to teach students how to be curious and inventive and provide them with the engineering methods and skills to answer their own curiosity.

Teaching Engineering

The first step is to teach the students how to build something that stays together and begin to understand the design process. We have found the best way is to introduce them to a drop test (releasing a structure from ankle, knee or hip height). For instance, the wall in figure 5 was built by a 5 year old. One can see that it has a weak section where the bricks do not overlap. No matter how many times we tell or show the proper building techniques, students continue to build a wall in this fashion. After the first drop test, however, they see that their wall breaks right along the crack and they do not do it again. Kindergartners are also loath to rip apart something they have built to improve it —the redesign portion of the engineering design process. Since the wall breaks with the drop test, this is no longer an issue. This particular test is also quite useful at the college-level. College students tend to have complicated robots instead of a simple wall but the structural integrity still needs to be evaluated.

The idea of sturdy structures and the design process are reinforced through similar activities. For instance, one can require the students to build a chair to support the weight of a stuffed animal or a

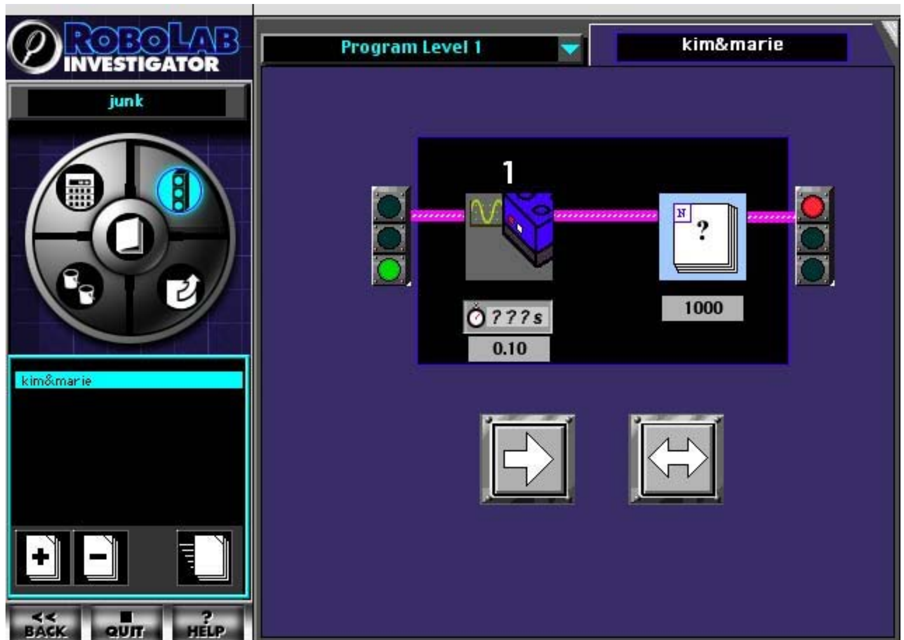

Figure 4: Investigator allows you to program the RCX to collect data points by specifying time between samples and total sampling time.

cup of water. One could also propose building a box to protect marshmallows or even a slice of pizza. The ability to easily extend activities is a powerful feature of the LEGO toolset as it allows for all students to stay engaged and on task even if they are working at different rates. Extensions can be related to student interest and curiosity.

Gearing is another concept that we start early on and continue through college. Students do not readily see why they want to gear the motors or how the gears work. We start them off with just

time between samples and total sampling time.

Grade	Engineering concepts	Science and math concepts
Kindergarten	Sturdy structures Elementary programming	Forces
1st grade	Sturdy structures Gearing and motion	Forces and torques Prediction and estimation
2nd grade	Sturdy structures Gearing and motion Levers and pulleys	Decimal numbers Mechanical advantage Graph generation
3rd grade	Sturdy structures Gearing and motion Modeling and calibration	Graph interpolation and extrapolation Multiplication applications
4th grade	Advanced programming and automation Hypothesis testing	Scientific method Design of experiments
5th grade	Re-design and optimization Competition and collaboration	Heat transfer Acids and bases Scientific method

Table 1: Outline of Basic Sequence of Topics

assembling gear walls, letting them play with how to make the gears mesh and how they change direction. Then we teach them how to connect a motor to the gears and how to connect the motor to the RCX. Most students initially expect that if a motor is somewhere on their car, it will automatically work and are surprised when they turn the RCX on and nothing happens. First they experiment with just connecting the motor to the RCX and then connecting the motor to the gears. Finally, we show them how to attach the gears to the wheels, and now they have a geared car. Armed with this knowledge, we then challenge them to drive up an inclined surface. A surprisingly large number of students will discard all of their newly learned information on the gearing and simply connect the wheels directly to the motors. Their car moves much faster on the flat land and they are sure they are going to be able to climb the ramp. Inevitably they aren't able to, leading to great in-class discussions. We often add the drop-test to the challenge, requiring them to drop their car before it starts to drive *(Note: This can damage the RCX and motor*s).

Teaching Math

One of the real strengths of engineering is its reliance on other subjects (from reading to physics). This makes it fairly easy to bring in almost any subject. To introduce the concept of fractions and decimal numbers in the 2nd grade we use an exercise called "Going the Distance". The idea is to build a rover (Figure 6) that can drive to specific locations on a carpet of the United States. Students are to program their cars to go from Massachusetts to California. Driving for 1 second might get them to Colorado, whereas driving for 2 seconds puts them in Hawaii. Therefore, they need to choose a number between 1 and 2. One of the more interesting stories that has come from this exercise was a result of the programming software. Using a Pilot Level 1, they can type in the time to move, and students would type in 1.5; the display would show 1.50 and the students would get frustrated. "I wanted one point five, not one point fifty," is a common lament. Not only do they learn that 1.5 and 1.50 are the same, but they also see that 1.6 is greater than 1.4 since their car goes further when programmed for the former.

This exercise is easily extended for older children. In the fourth and fifth grades, we have the students build a calibration plot of time versus distance. They check for repeatability of their cars as well as effective methods of making their cars go straight (for instance, using only one motor and big wheels in the front). In the final competition, students are told to program their cars to go a specific distance, but are not allowed to test them. They learn how to interpolate (or extrapolate) from their data and the person whose car comes closest to the given distance wins. One can add a new dimension to the problem by putting a LEGO person at the appropriate distance and the winner is the car which comes closest to the LEGO person without knocking it over ("kissing"). We have used the same problem at the college level, where even the effects of startup and stopping are accounted for in the calibration. Finally, one can do the same exercise over the Internet, using the remote control feature of the hardware and software, at the SENSORS site (http://www.ceeo.tufts.edu/sensors/). [27]


Figure 5: A poorly constructed wall

Teaching Reading and Writing

We have also used the LEGO bricks to teach reading and writing skills in the elementary school. We have used "visual reading" in most pre-college grades, tasking the students to build what they read. We have found that this results in a number of discussions about the book, from quoting the number of windows in a castle to discussing what the author meant in certain passages. Some teachers have extended the visual reading work into teaching math as well. For instance, one 2nd grade teacher had the students build the amusement park in Charlotte's Web (E.B. White). Once the amusement park was built, students were given play money and "attended" the rides. The math lesson came in giving correct change for the rides. Another teacher took a different approach and gave each student group a budget for their ride and then assigned a price to each LEGO brick. Popular bricks (people, trees, etc.) cost substantially more than common bricks. This approach has the math advantage as well as the demonstration of designing to a bud-

Figure 6: Going the Distance

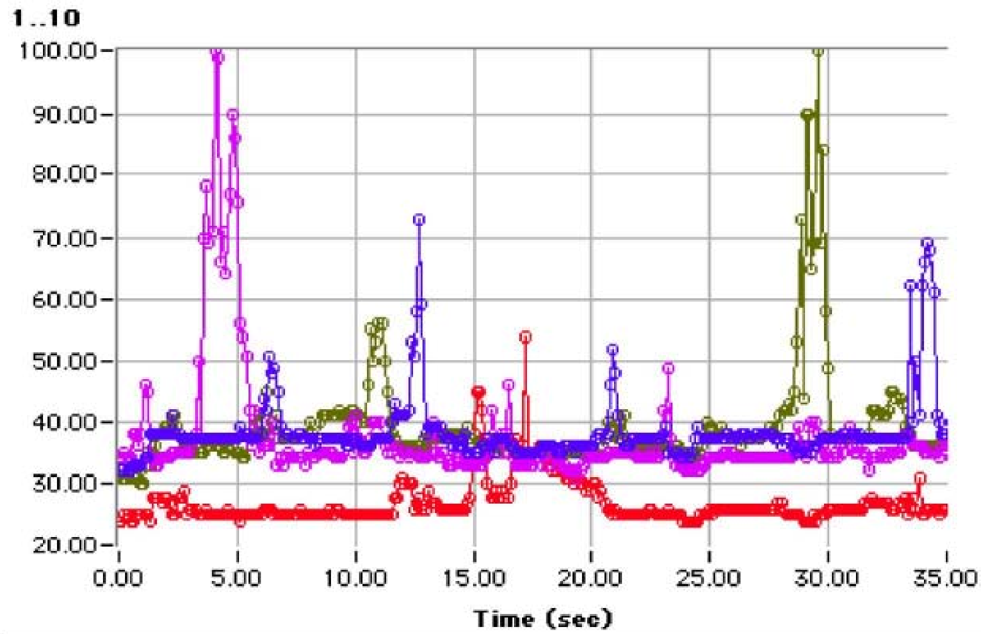

Figure 7: Sample data set from the Burglar activity. Peaks indicate when the flashlight passed by the RCX.

get. Many of the elements of engineering such as sturdy structures, gearing, pulleys, and redesign are prevalent in a secondary nature in these projects as well.

Another approach to teaching reading and writing as well as engineering is through the making of a movie. After reading a book in class, the students reduce the book to a 10-minute script. Reading comprehension is tested in the many ensuing discussions of what is important and not important to the book, as they write the script. They then break into groups and construct the scenery and props for the movie from LEGO bricks and other materials. We have done this with everything from "The Lorax" in 1st grade to 6th graders filming "The Wind in the Willows". A tool for making stop action movies with ROBOLAB is currently in development at Tufts.

Science Investigations

We also use ROBOLAB in the classroom to teach investigation skills, along with the math and science necessary to understand and interpret the results. We start in the 3rd grade with an exercise called "The Burglar" where each group of students programs their RCX to take light sensor measurements over a 5-minute period. After discussing with the students the possible pitfalls of a poorly chosen sampling rate, the class decides on a sampling rate for their RCXs and then puts them throughout the classroom. All students then leave the classroom and the overhead lights are turned off. The teacher then walks through the classroom with a flashlight. All students return and the data from the RCXs are combined on an overhead projector. Figure 7 shows a sample data set. Each color corresponds to the data from a different RCX. From the peaks, the students can determine when the teacher passed their particular RCX and therefore surmise the path of the teacher through the classroom.

One of the most engaging and entertaining exercises we do in the investigative area is "Finding the Letter". We have done this in many different guises (including on the web at http://www.ceeo.tufts.edu/sensors/), always with great enthusiasm from the students. The idea is to print out a letter so that it takes up an entire 8" x11" piece of paper. Paste this letter on the floor and then cover the letter with a sheet – so that no one can see it. Then allow the students to drive a vehicle under the sheet with the light sensor pointing down. Using their light sensor readings and doing multiple passes, they then guess the letter. Usually they can do it in 4 – 5 passes. The best part of this exercise is watching them reduce the number of possible

Figure 8: The LEGO Builder

letters with each pass. The engineering learning comes from the construction and programming of the rover. The math lesson comes in the interpretation of the plots along with the determination of the sampling rates

Traditional science investigations can be done as well. By hanging the RCX with a light sensor pointing downward and swinging it as a pendulum the period of the pendulum can be measured by looking at the light sensor readings logged. More accurate readings can be measured by swinging the RCX over a black and white piece of paper. Advanced students can use this measurement to estimate the gravitational acceleration. In another experiment, fourth grade students have measured the cooling rates of a cup of water using the LEGO temperature sensor. This led to an energetic discussion of what a temperature change meant on a molecular level, with one perceptive student noting that ice melts more slowly in air than in water as the molecules in the water are closer together and therefore impact the ice more often and remove energy more quickly. Again the success of these investigations is apparent in the discussions and enthusiasm of the students.

The College Level Ceiling

Using the same tools (hardware and software) we have taught a number of engineering concepts in college. Much of this work has been reported in conference proceedings, journals, [11,17,24] and at the ROBOLAB@CEEO Website. [26] Probably the most complicated construction we have done to date is the LEGO builder (Figure 8). The user specifies a wall they want constructed (color and size) and then throws a number of pieces on the table. The LEGO camera identifies the correct piece and sends the robotic arm to pick it up. Using the camera information, the arm rotates to the correct orientation, picks the piece up, and brings it back to add to the wall.

College students have built a large number of other great projects, learning many engineering concepts along the way. Many of these projects require team skills, communication skills, economic analyses, and advanced programming and algorithmic development. All can be done without LEGO bricks and ROBOLAB, but these tools allow students to prototype and test more rapidly (and for less cost) than with many traditional materials, and they bring a lot of excitement with them. We also have used the ROBOLAB toolset to teach LabVIEW and experimentation techniques to the mechanical engineering undergraduates [24] and to teach engineering to liberal arts students. [11] The main point is that the high ceiling of the toolset allows complexities well beyond the abilities of most pre-college students. With this range, all students in any one class, regardless of their abilities, can participate and be challenged. Some of the challenges may be above water while others are below (Figure 9).

ROBOLAB Successes

The ability of the ROBOLAB toolset to successfully bring engineering into the classroom can be measured in numerous ways. At the micro-scale, we can look at the success of a single student. We have qualitatively assessed their engineering abilities in a number of ways. Students write engineering logs, and teachers have looked at changes in design complexity and sturdiness, the use of gearing, and the application of the math and science principles. For instance, in one 4th grade classroom, students learned about torque and used their math skills to predict the increase in torque due to their gearing and then tested their prediction. We have also looked for students remembering what they learned last year and applying it. Older students, for example, voluntarily dropping their construction to demonstrate its sturdiness.

At the mezzo-scale, we can look at the success in a single school. Lincoln School in Massachusetts has been teaching engineering in classrooms for 10 years. It started out with just a few teachers experimenting with some LEGO engineering challenges once or twice during the year. Here the program's success can be measured by the fact that the teachers decided to adopt the program as a school and now almost every teacher from kindergarten to 6th grade is using the ROBOLAB toolset as a significant portion of their curriculum. The fact that this was a teacher-led change, not an administrator-led change is indicative too of the program's success. They have done this in part because of the huge response they have received from the students. The excitement generated from the engineering has led to kids spending recesses building, to kids working with their younger sibling's class, and to parents becoming more involved in their child's education.

At the macro-scale, the ROBOLAB product has been internationally successful, with an estimated 1 million students, (from kindergarten through college) a year using it around the world. It has been translated into 14 different languages and has led to international collaborations – with students from Singapore, New Zealand, and Boston all sharing ideas and construction challenges. In the past two years, ROBOLAB has won a number of awards including—the BETT award for best educational software in Great Britain, The World Didact Gold Medal (Switzerland), MacEddy Award by MacUser for best educational product (USA) and a DIGITA (Germany) prize, as well as a number of other, smaller, soft-

Figure 9: A LEGO Remotely Operated Underwater Vehicle

ware awards.

Lessons Learned: Working in the Classroom

Although the success of ROBOLAB has been very rewarding, there are a number of lessons we learned, often the hard way. There are difficulties associated with product development, product dissemination, and product support. Many of these issues are small for a single classroom or single school, but become huge when it is tens of thousands of schools. We found the two most important parts of ROBOLAB are the forming of strategic alliances with industry, and working in the schools to get firsthand feedback. The LEGO and NI alliance has allowed the product to grow very fast. It has allowed us to really bring engineering into a far greater number of schools than we had ever imagined. The second part is actually being part of the classroom, seeing the issues the teachers and students face. One cannot study education from afar.

Making a systemic change in a curriculum requires a large effort on the part of the teachers, administrators, parents, and the kids and takes a long time to happen. It requires continual financial support and, when it is something completely new, it requires intellectual support. Finally, it has to be hands-on and open-ended so that all can create and thereby gain ownership of the concepts being taught. In this section we outline some of the observations we have made in changing a school system; how to support the teachers in entering a new field and how a child's gender or learning style will have a profound affect on their approach and resulting construction.

Working with teachers

The LEGO engineering curriculum brings with it a number of issues in the classroom, making life harder for the teacher. Batteries can die, computers can crash, and students can have their RCX mistakenly reprogrammed. The teaching style and material is very different from the conventional method. Hands on projects do not have one right answer and the teacher will often not know the answer to the students' questions that arise. Most of the student learning comes from discussions and the teacher asking penetrating questions. This is difficult to do if the teacher is trying to change batteries, reboot a computer, and get the kids to share the LEGO bricks at the same time. Most elementary school teachers do not have engineering training, nor do they have training in physics or programming. For these reasons, they need to have support in the classroom. This can come from parents, older students, undergraduate engineering students, or professional engineers in industry.

At Tufts we have started a number of support programs for the teachers. Multiple professors, staff members, and students go into the classrooms every week to assist the teachers, hold monthly teacher support meetings, and train them on new aspects of the hardware or software and sharing ideas, and issues. We also run workshops every year for parents. The idea is to get parents involved and to get them helping out in classrooms. Finally, we have a new grant funded program at Tufts that pays Tufts engineering students to go into classrooms and help out. In all of these cases, it is important that the parent or student do not take over the classroom. It is a lot easier to come into a classroom, run a "wiz-bang" presentation for the kids and leave. This approach, however, will not change the classroom. The teacher must be the driving force and the parent, student or professor must be there only to help with hardware and software problems and free up the teacher's time so that the teacher can wander about asking questions about the math, science, and engineering. In general, we have found without this kind of support, the classrooms will often revert to "LEGO playtime" instead of a real learning experience. On the other hand, when this support relationship works, it is impressive what children can learn, from discovering molecular thermodynamics in 4^{th} grade to frictional forces in 1^{st}.

Gender Differences

In bringing LEGO Engineering into the classroom, we have noticed a decided gender difference. The first time a classroom embarks on a construction problem, many of the girls will mention that they do not build with LEGOs although their brother does. This finding is in keeping with much of the research that shows that boys have more experiences with items and topics related to physical science outside the classroom. [6,13-16] In general, we have found that the girls tend to design before building, whereas the boys start building before they have really thought about designing. Girls will work better as a team – talking among themselves about a design before building. The boys would much rather be on their own, often leading to more arguments than discussions in groups. Because the girls tend to think before building and the boys tend to build before thinking, mixed-gender groups often have some problems as once the girls have a design idea; the boys are not willing to break apart what they have built already (and there aren't a lot of pieces left for the girls to choose from). We have found that one can partially solve this by requiring paper drawings before attacking the LEGO bricks. Also, in classrooms that have done this for a while, the girls have learned to be more forceful in making sure their design gets consideration. The students in general have learned to be better at working as a team.

Research on the aspects of science that girls enjoy indicates that girls prefer topics that have relevance to the surrounding world. [1,18] Our qualitative observations of girls reflect these findings as well. We have found that the girls tend to prefer design problems that have a purpose or meaning. For instance, the girls will much prefer building a hospital, or a ski resort, whereas the boys will focus on one thing – the fastest ambulance or the biggest ski lift. If a teacher gives the classroom the assignment of building a car – the boys are happy. If the teacher gives the assignment of trying to identify the unknown letter and to do that you will have to build a car – the girls are happy. Girls are often more interested in the investigative portion of the ROBOLAB toolkit. They like the deduction and modeling aspects. Of course in all cases, one can find girls that behave like the description of the boy and visa versa, but on average these traits seem to hold across ethnicity, cultures, and socio-economic background.

It is interesting to note that these characteristics are not restricted to the kids. Parents and teachers taking workshops behave in the same way. The males tend to work individually and start building right away. The females tend to work in groups, discussing first what they want to build. The males will zero in on one thing and just build that whereas the females will build to the "bigger picture" by adding details. For instance at one parent night we challenged them to build a shopping mall. The males spent the entire hour building the escalator. The females built multiple stores with storefronts, doors, lights etc. The escalator was much too fast for any human to survive the trip and was much too big to fit with the rest of the mall. Similar to the boys, however, the men were very excited and thought it awesome, without any thoughts of slowing it down or making it fit with the rest of the design.

Engineering for Everyone

One of the more unique attributes of the LEGO Engineering program is that all students are always excited about it and it holds their attention for as long as the teacher is willing or able to give. Teachers are always surprised at how long even the younger kids stay on task and complain when the time is over. Students will stay in during recess or come early to improve their projects. One classroom was studying trebuchets, and the teacher announced that those interested could come in during lunchtime to build one. Twenty-four children showed up at lunch – about half boys and half girls – which was especially impressive since the class only had 21 students to begin with.

Children (and adults) have a wide variation in learning styles and intelligences– from those who have excellent memories and learn by memorizing facts to those who learn best through visual and hands-on interaction.[26] High stakes standardized testing forces a lot of teaching to focus on topics that are easily pencil and paper testable. Students with excellent memories and the ability to sit still for long periods of time succeed at these tests and are identified as "intelligent". [27] While the intelligence of students who are able to quickly interpolate a graph or build and explain a complex gear system but are slow to memorize their multiplication tables is not necessarily recognized or appreciated. Designing, building and programming invoke knowledge, intelligences and learning styles not often used or valued in a traditional classroom. We continually see students that are at the bottom of the traditional classroom become "experts" as they excel in these areas and suddenly find themselves respected by both the teachers and the students. Other similar projects have found that hands-on technology projects are effective in teaching students classified as learning disabled. [4] Numerous teachers we work with have found that students with attention-deficit disorder (ADD) have become interested in schoolwork and will sit still during class so that they can get time to work on their construction.

Summary

In conclusion, we have developed an effective platform to teach engineering in schools. This platform is flexible enough to allow students to build almost anything, complex enough to challenge a graduate student in engineering, and simple enough to be used by a kindergartner. We have been successful in integrating this toolset into classrooms and through it changing the way math and science are taught. We have presented some of the ways that people can integrate this material into their own school and used these examples to show how the students learned the material with their hands. We have worked with school systems to initiate a systemic change or just start a small after-school program or summer camp.

Before any of this enters the classroom, the teacher must sit down and really decide what it is she wants to teach. We feel that the most important things to teach are

1. curiosity,
2. enthusiasm for learning,
3. self-confidence,
4. how to find answers, and
5. how to test validity of answers.

These goals are true at kindergarten and in college, and armed with these capabilities, the students can successfully attack problems of any discipline. Engineering teaches to all of these goals independent of the age of the student. Engineering might not be a discipline that people expect to find in elementary or even secondary school but it is a powerful way of teaching, learning, and extending education methods. The interest and excitement that engineering and the LEGO/ROBOLAB toolset inspire provide the basis for rich learning opportunities that span math, science, reading, and more. Its low entry and high ceiling that allows students to grow and work with it for many years minimizing time spent learning new tools and maximizing learning time. Moreover, LEGO-based engineering design projects, when presented in the proper context, can provide hands-on opportunities for girls at a very young age thus helping to build and develop their confidence and interest in math, science, and engineering. Its appeal to multiple learning styles makes it a unique tool for reaching different types of students and allowing them to succeed in ways not possible with more traditional teaching methods and materials. There are significant challenges in terms of supporting this new discipline and way of learning in the classroom setting but involving the community of parents, students, and industry is one promising solution.

References

1. T. Andre, M. Whigham, A. Hendrickson,, and S. Chambers, "Competency beliefs, positive affect, and gender stereotypes of elementary students and their parents about science versus other school subjects." *Journal of Research in Science Teaching*, *36(6)*, 719-747. 1999.

2. Dave Baum, Michael Gasperi, Ralph Hempel, and Luis Villa, *Extreme Lego Mindstorms: An Advanced Guide to Lego Mindstorms*. Apress, 2000.

3. Dave Baum, and Rodd Zurcher, *Dave Baum's Definitive Guide to LEGO Mindstorms (Technology in Action).* Apress, 2000.

4. B.A. Bottge, Heinrichs, Z.D. Mehta, and Y Hung, "Weighing the Benefits of Anchored Math Instruction for Students with Disabilities in General Education Classes." *The Journal of Special Education*, 35(4), 186-200. 2002.

5. Jerome S. Bruner, *The process of education.* Cambridge, Harvard University Press 1963.

6. S. Catsambis, Gender, race, ethnicity, and science education in the middle grades. *Journal of Research in Science Teaching, 32, 243-257. 1995*.

7. Martha Cyr, Mindstorms for Schools, *ROBOLAB Getting Started 1, Teacher's Guide for ROBOLAB Software*, 1998.

8. Martha Cyr, Mindstorms for Schools, *ROBOLAB Getting Started 2, Teacher's Guide for ROBOLAB Software*,1999.

9. Martha Cyr, Mindstorms for Schools*, ROBOLAB Getting Started 3, Teacher's Guide for ROBOLAB Software*, 2001.

10. Russell Davis, "Learning How To Learn: Technology, the Seven Multiple Intelligences and Learning." California: ERIC Clearinghouse (ERIC Document Reproduction Service No. ED 338214).

11. Benjamin Erwin, Martha Cyr, and Chris Rogers, "LEGO Engineer and ROBOLAB: Teaching Engineering with LabVIEW from Kindergarten to Graduate School." Vol 16., No. 3 *International Journal of Engineering Education*, 2000.

12. Howard Gardner, *Frames of Mind: the Theory of Multiple Intelligences*. NY: Basic Books 1983.

13. T. Greenfield, "Gender, ethnicity, science achievement, and attitudes." *Journal of Research in Science Teaching*, *33(8),* 259-275. 1996.

14. G.M. Jones, A. Howe, and M.J Rua, "Gender differences in students' experiences, interests, and attitudes towards science and scientists." *Science Education*, *84(2),* 180192. 2000.

15. J.B. Kahle, and M.K. Lakes, "The myth of equality in science classrooms." *Journal of Research in Science Teaching*, *20(2)*, 131-140. 1983.

16. J.B. Kahle, M.L. Matyas, and H. Cho, "An assessment of the impact of science experiences on the career choices of male and female biology students." *Journal of Research in Science Teaching*, *22(5),* 385-394. 1985.

17. Philip Lau, Scott McNamara, Chris Rogers, and Merredith Portsmore, "LEGO Robotics in Engineering." *Proceedings of the American Society of Engineering Education Annual Exposition and Conference, New Mexico*, June 2001.

18. H. Marsh and A. Yeung, "The distinctiveness of affects in specific school subjects: An application of confirmatory factor analysis with the national educational longitudinal study of 1988." *American Educational Research Journal*, 33(3), 665-689. 1996.

19. Seymour Papert, *Mindstorms: children, computers, and powerful ideas.* New York: Basic Books. 1980.

20. Seymour Papert, "What's the big idea? Towards a pedagogy of idea power." *IBM Systems Journal*. 39 (3/4). Available WWW: http://www.research.ibm.com/journal/sj/393/part2/papert.html 2000.

21. G. Pearson and A. Young, Technically Speaking, Why All Americans need to know more about technology. National Academy Press, Washington, D.C.. 2002,

22. Merredith Portsmore, Martha Cyr, and Chris Rogers, "Integrating the Internet, LabVIEW, and

Lego Bricks into Modular Data Acquisition and Analysis Software for K-College." *Computers in Education Journal*. Vol. XI April-June 2001. pg 21-29.

23. Merredith Portsmore, "ROBOLAB: Intuitive Robotic Programming Software to Support Life Long Learning", APPLE Learning Technology Review, Spring/Summer 1999.

24. Chris Rogers and Merredith Portsmore, "Data acquisition in the dorm room: Teaching experimentation techniques using LEGO Materials." *Proceedings of the American Society of Engineering Education Annual Exposition and Conference, New Mexico*, June 2001.

25. Tufts' Center For Engineering Educational Outreach, "Center For Engineering Educational Outreach,",(2004) http://www.ceeo.tufts.edu

26. Tufts' Center For Engineering Educational Outreach, "ROBOLAB@CEEO" (2004) – Available WWW: http://www.ceeo.tufts.edu/robolabatceeo

27. Tufts' Center For Engineering Educational Outreach, "SENSORS (Science Engineering NASA Site of Remote Sensing)" (2003) – Available WWW: http:// www.ceeo.tufts.edu/sensors

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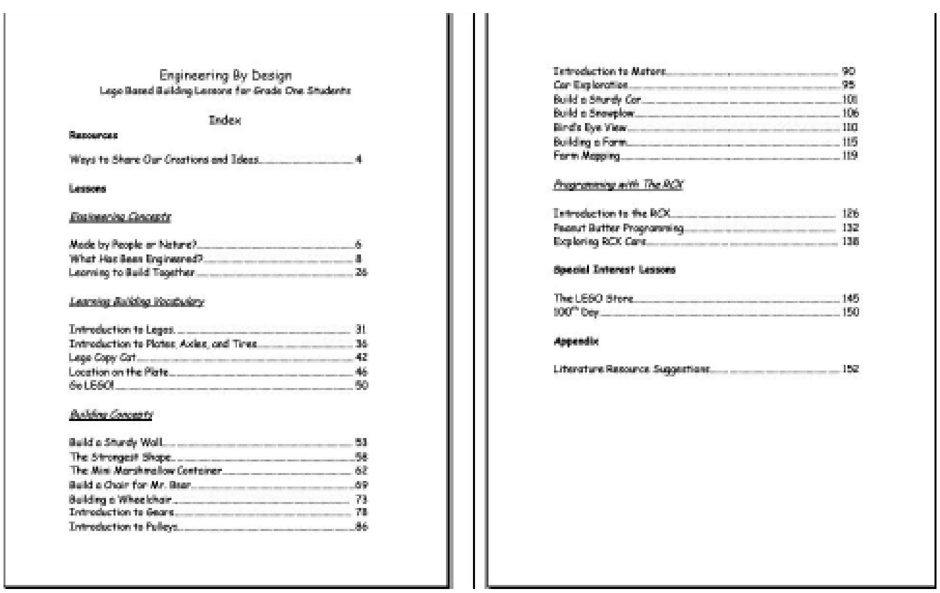
Chris Rogers is a professor of mechanical engineering at Tufts University and director of Tufts' Center for Engineering Educational outreach. His first sabbatical was spent at Harvard and a local kindergarten looking at methods of teaching engineering. He spent half a year in New Zealand on a Fulbright Scholarship looking at 3D reconstruction of flame fronts to estimate heat fluxes. Last year, Chris was at Princeton as the Kenan Professor of Distinguished Teaching where he worked on developing new ways to assess and value teaching. He has received the 2003 NSF Director's Distinguished Teaching Scholar Award for excellence in both teaching and research and the 1998 Carnegie Professor of the Year in Massachusetts Award. Chris is involved in six different research areas: particle-laden flows (a continuation of his thesis), telerobotics and controls, slurry flows in chemical-mechanical planarization, the engineering of musical instruments, measuring flame shapes of couch fires, and in elementary school engineering education. He has worked with LEGO to develop ROBOLAB and is considered by some to be the "Father of ROBOLAB." He works in various classrooms once a week, although he has been banned from recess for making too much noise. Most importantly, he has three kids -all brilliant -who are responsible for most of his research interests and efforts.

Merredith Portsmore is a Ph.D Candidate at Tufts University in Engineering Education. She received undergraduate degrees in Mechanical Engineering and English at Tufts as well as a Master's in Education. Prior to returning to school, she worked at the Center for Engineering Educational Outreach for 4 years supporting the development of ROBOLAB and creating web based resources to support educators using ROBOLAB. She is currently working on deploying a web-based museum (http://www.ceeo.tufts.edu/kime) that will facilitate kids from around the world to sharing science, math, and engineering projects.

Appendix A – Tufts' Center for Engineering Educational Outreach Lego Engineering Resources

The main dissemination site for the Center for Engineering Educational Outreach's Lego Engineering Resources is the ROBOLAB@CEEO web site (http://www.ceeo.tufts.edu/robolabatceeo). The site features a database of 40 individual activities (Figure A1), multi-week curriculum units (Figure A2), classroom hints and help, a LEGO piece archive, and a physics concept reference(Figure A3). In addition the site hosts a gallery of projects, tutorials on high end ROBOLAB based image processing, patches for ROBOLAB, and related presentations and papers. The entire site is currently free to the public.

Figure A1. *Individual Activities detail the materials needed, the standards addressed, the steps from implementation, and include links to worksheets and sample programs.*



Engineering By Design

Lego Based Building Lessons for Grade One Students

Index

Figure A2. *The Table of Contents for an 18-24 week first grade engineering curriculum.*

Figure A3. The Physics Concepts guide explains physics concepts and links them to related LEGO activities