BLOCKS TO ROBOTS

LEARNING WITH TECHNOLOGY IN THE EARLY CHILDHOOD CLASSROOM

Marina Umaschi Bers

FOREWORD BY DAVID ELKIND

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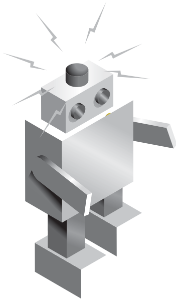

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Learning with Technology in the Early Childhood Classroom

MARINA UMASCHI BERS

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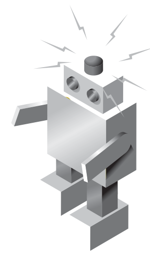

This book is dedicated to the memory of my father,
Hector Umaschi

and to my young children,
Tali, Alan, and Nico, who are the future

Rabbi Tarfon said: It is not your obligation to complete the work, but neither are you free to desist from it.

—Pirke Avot 11:21 (*Ethics of Our Fathers*)

Contents

Foreword

What can young children learn and when? This has become a hotly disputed subject as we move into the 21st century. On one side of the issue are those who believe that even young children can be taught the three R's and more. Many kindergartens are now teaching reading and arithmetic, not just letters and numbers. Testing and homework are also not uncommon among the preschool set. On the other side are those who argue that young children have much to learn before they should be exposed to academics, which—in any case—are inappropriate for their needs, interests, and level of mental ability.

Marina Bers now enters this controversy from an entirely different direction, namely that of electronic media and robotics. She argues that, over the last few decades, we have entered a new reality of atoms and bits, of mechanical devices that are now run by electronics. To be sure, the union of machines and electronics is not entirely new. The telegraph, the telephone, the radio, and the electric clock are all early examples of the union of mechanics and electronics.

What is new today is the miniaturization of the electronics and our vastly increased ability to become actively involved in the translation of the mechanical into the electronic. Turning on a light switch or other electrical device is the simplest form of this active translation. But this and similar on/off translations are relatively passive and automatic; they require little thought. With the introduction of the computer we have become much more active intermediaries in the translation process. And this active role has become ever more extensive with the introduction of other electronic devices such as computer games and BlackBerry® devices. Our active involvement in the conversion of the mechanical into the electronic is what is unique about our contemporary computer age. It has the potential to change the way we think about ourselves and our world (Papert, 1980).

It was Marshall McLuhan (1964) who first suggested that the "medium is the message"—that the advent of electronic media would have the same impact on culture and society as did the advent of print media in the 14th century. In moving from an oral to a print culture, McLuhan argued, we also moved from an oral culture that was based on memory to a print culture that liberated abstract thought. In the same way, McLuhan argued that electronic media would also change the way we think about and perceive our world. That was the message.

Seymour Papert (1980), Marina Bers's mentor at MIT, combined McLuhan's argument with the theory of intellectual development championed by his mentor, Jean Piaget (1950). Piaget created a constructivist epistemology in which he demonstrated that children construct and reconstruct reality out of their experiences with the environment. Piaget's view was in sharp contrast to traditional learning theory, which defined learning as "the modification of behavior as a result of experience." Instead, Piaget argued that learning could also be defined as "the modification of experience as the result of behavior." In effect, children create their own learning experiences. A child who babbles, for example, creates all of the sounds he or she needs to learn to speak his or her native language.

Papert went beyond Piaget to suggest, as McLuhan had, that electronic media can give rise to new ways of thinking. He argues that with our new technology children can now create their own objects that integrate the mechanical with the electronic. These inventive constructions give rise to a new mode of thinking that Papert calls *constructionism*. That is to say, when children build their own mechanical/electronic objects, they have created experience from which they learn new concepts of space, time, and causality. Indeed, in this self-created virtual world, space has become portable, time has become retrievable, and causality has become programmable.

It is Papert's constructionism, the idea that children create their own object realities and learn from them, combined with other contemporary ideas, that informs Bers's approach to early childhood education. She argues, as did many of the early childhood educators before her, that young children learn best through their own self-directed activity. What is different is that Bers provides an alternative to the traditional static manipulatives, such as blocks, sticks, and color skeins. Bers believes that children work just as readily with manipulatives that are dynamic.

Papert's Logo®, a program in which children learn to build and operate a turtle* electronically, is the prototype for this kind of dynamic manipulation. On the computer screen children manipulate icons that transmit signals to their self-constructed objects. These objects—robots—can then be directed to engage in a variety of simple activities. Thus, constructionism brings both design and engineering into the process of constructing and then programming objects.

Bers, however, has gone further than Papert in extending the notion of allowing children to create their own object-created environments—to the creation of social environments. The Zora program she has created allows children to construct their own spatial reality, in which they can adopt various alternative identities (Bers, 2001, 2006). In addition, she has built upon the Reggio Emilia framework (Edwards, Gandini, & Forman, 1998), as well as others, to make this approach extend to all facets of early childhood education, from curriculum to assessment to classroom management.

This groundbreaking account of Bers's work is divided into two Parts. In the first Part, Bers deals with the broad issue of childhood and technology. In Chapter 1 she presents a discussion of constructionism and its four basic subconcepts: learning by designing within a community, technological tools for learning, powerful ideas and wonderful ideas, and learning about learning with technology. In Chapter 2 she elaborates, and concretizes the theoretical discussion by showing how constructionism can be applied to social emotional learning. She further illustrates the application of these ideas with two different classroom vignettes.

The second Part of the book looks at the issue of developmentally appropriate practice with robotics. In Chapter 3 Bers describes how the construction of robotics can serve as a powerful learning tool even for young children. Chapter 4 provides guidance for teachers who are

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*The "turtle" was originally a mobile robot shaped in the form of a large turtle. It contained a small computer that was operated by a hand-held remote control. The "turtle" moved on the floor. Eventually, the "turtle" appeared on a computer screen as a cursor in software for Atari. The child could then use the computer keyboard or mouse to move the cursor turtle to create geometric shapes of varying complexity.

interested in designing a learning environment that is centered about the use of robotics as manipulatives. These two chapters are again followed by a couple of vignettes illustrating how these ideas can be translated into classroom practice. One vignette deals with children learning about local history and the other with using design as an instructional tool.

I believe that this is a seminal work. It is suggestive as well as substantive. Because the field is so new, many of the ideas are not fully developed. Yet, in attempting to extend this atoms-and-bits approach to all facets of early childhood education, Bers has provided both teachers and researchers with many new vistas onto the domain of early childhood teaching and research. Much of the material and research she cites is probably unfamiliar to most early childhood educators. Marina Bers has thus done a most valuable service in bringing this information to their attention. In addition, she has provided abundant illustrations of how constructionism can be introduced into the early childhood classroom. In so doing, she has presented a fresh, exciting, and challenging approach to the education of young children.

—David Elkind

INTRODUCTION

Playful Learning

Little Robots, Big Ideas

We are surrounded by technology—from the chairs we sit on to the computers on our desks, from the pencil to high-tech digital ink. However, in the early grades children learn very little about this world of technology. Over the past few decades and beyond, the early childhood science curriculum has focused on the natural world: bugs and insects, plants and the Arctic. While this knowledge is important, in today's society developing early knowledge about our man-made world is just as important. That area of knowledge is the realm of technology and engineering, which focuses on the development and application of tools, machines, materials, and processes that help to solve human problems.

Early childhood experience hasn't completely ignored the technological; it is common to see young children using cardboard or recycling materials to build cities and bridges. However, what is unique to our man-made world today is that atoms are not enough. Bits are just as important. Computers and electronics are as much a part of our world as gears and mechanical structures.

We go to the bathroom to wash our hands and the faucets "know" when to start dispensing water and when we are done. The elevator "knows" when someone's little hands are between the doors and they shouldn't close. Our cell phones "know" how to take pictures, send e-mails, and behave as alarm clocks. Even our cars "know" where we want to go, and they can take us there without getting lost. We live in a world in which bits and atoms are increasingly becoming integrated

(Gershenfeld, 1999). However, we continue teaching our children about atoms and bits as two separate realms of experience. In the early schooling experiences, we teach them about polar bears and cacti, which are probably further from their everyday experience than smart faucets and cell phones.

This book is about how we can start helping our young to explore the modern world of bits and atoms. The spirit of how to do this follows the early childhood teaching tradition started when Fröebel invented kindergarten in the 1800s: using manipulative materials. This book is about a new kind of material, robotic manipulatives, which integrate atoms and bits. While using these tools, children can learn about sensors, motors, and the digital domain in a playful way by building their own cars that follow a light, elevators that work with a touch sensor, or puppets that play music. Young children can become engineers by playing with gears, levers, joints, motors, sensors, and programming loops, and they can become storytellers by creating their own meaningful projects that move in response to a stimulus (either another robot or the environment). Figures 1, 2, and 3 provide exam-

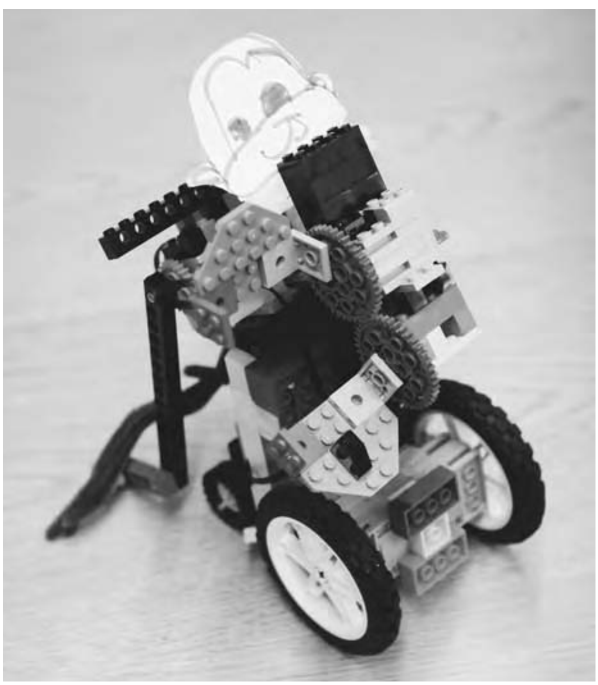

FIGURE 1. A monkey robot built by a first-grader

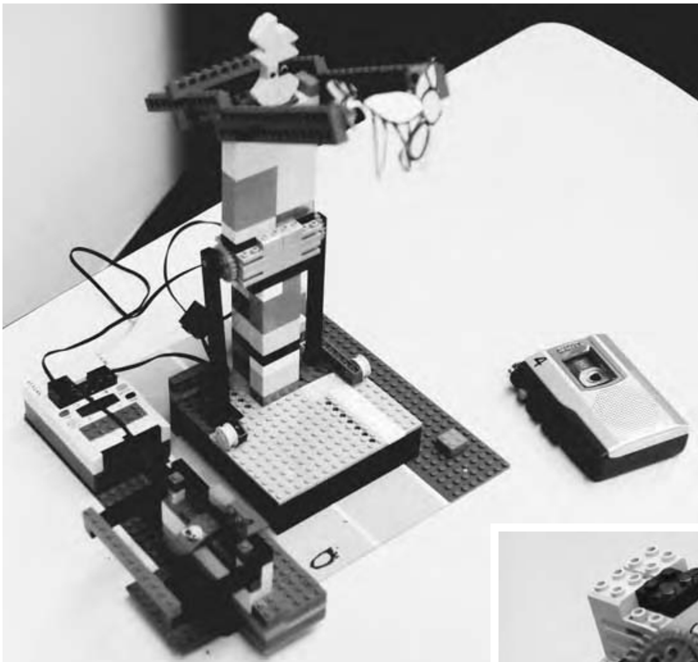

FIGURE 2. A robotic juggler

FIGURE 3. Making a swing set

ples of different LEGO®-based robotics projects done by 6- and 7-year-old children working in an after-school robotics workshop held at Tufts University's Department of Child Development.

Robotic manipulatives are a gateway for helping children learn about mathematical concepts and the scientific method of inquiry. They also help develop technological fluency early on through the introduction of engineering and programming. By extending the potential of traditional manipulatives, they engage children in using their hands and developing fine motor skills, as well as hand–eye coordination. But most importantly, robotic manipulatives invite children to participate in social interactions and negotiations while playing to learn, and learning to play.

This book presents innovative work with robotic manipulatives in early childhood that is situated within the constructionist philosophy of using computers in education, which was developed by pioneer Seymour Papert. Papert, creator of the Logo language and the LEGO MINDSTORMS® robotics concept, worked with Jean Piaget in Geneva. Readers might be familiar with Piaget's concept of *constructivism.* This book focuses instead on *constructionism,* an approach that keeps constructivism's developmental stance but is explicitly conceived for teaching and learning with technology.

Constructionism asserts that computers are powerful educational technologies when used as tools for supporting the design, the construction, and the programming of projects people truly care about (Papert, 1980). By constructing an external object to reflect upon, people also construct internal knowledge. Constructionism has its roots in Piaget's constructivism (Piaget, 1971; Papert, 1999). However, whereas Piaget's theory was developed to explain how knowledge is constructed in our heads, Papert pays particular attention to the role of constructions in the world (specifically, robotic constructions) as a support for those in the head. Thus, constructionism is both a theory of learning and a strategy for education that offers the framework for developing a technology-rich, design-based learning environment. Independent learning and discovery happen best when children can make, create, program, and design their own "objects to think with" in a playful manner. Robotic manipulatives are certainly powerful "objects to think with." However, the technology by itself is not enough. There are many ways of using a powerful technology in a disempowering way. Therefore, this book offers an educational philosophy to empower children in the use of technology.

This volume addresses questions leading to an understanding of constructionism as a philosophy and pedagogy for using technology in early childhood: What is the constructionist educational philosophy? How is it different from constructivism and instructionism? Is constructionism a philosophy that can guide developmentally appropriate practice? How can it inform the use of robotics in early childhood? How can we promote socioemotional development through the use of robotics? What cultural contexts need to be in place for this work to be successful? This set of questions is addressed in Part I: "Constructionism: Technology and Early Childhood." An interview with an expert in sociocultural theories of child development and education, Dr. Rebecca S. New, offers a different perspective on these questions by focusing on conflicting views and anxieties regarding the developmental appropriateness of children's learning opportunities with robotics. Two vignettes written by innovative educators provide examples of how robotics is currently used in early childhood classrooms.

Whereas the first Part of the book focuses on the pedagogy and the philosophy that guide the work with robotic manipulatives (or any other technology), the second Part addresses questions leading to an understanding of the potential of, and challenges of, this new generation of manipulatives—robotics, such as: Why robotics in early childhood? What can be done with this new technology to improve children's learning, in particular in the areas of math, science, and technology? How can a teacher start this work in his or her own classroom? These questions are addressed in Part II: "Using Robotic Manipulatives in the Early Childhood Classroom." Examples of curricular activities for K–2 are provided, along with vignettes about experiences of using robotics in early childhood and how to approach classroom management in this context. An interview with a master teacher, Terry Green, who has been using robotics in the public school system for over 10 years, provides further insights of the challenges, possibilities, and issues to consider when approaching this work.

Most of the projects and examples discussed in this book use LEGO Mindstorms because it is the commercial robotics kit most widely available and supported for educational uses. However, the pedagogical and developmental theories presented go beyond this particular construction kit. They apply to any robotic manipulative or technology that allows children to combine bits and atoms to design a personally meaningful project that can exhibit behaviors by responding to inputs (Resnick, 1998).

As you read this book, you might become convinced of the opportunities (and challenges) of using robotic manipulatives in early childhood. However, where do you start? Chapter 4 provides a practical guide, with resources and recommendations to orient readers interested in exploring the use of robotics in early childhood. It is not intended to be a comprehensive how-to manual but instead is a first introduction to how to approach the topic and where to find more information. Rather than offering a prescribed set of rules or a toolbox for putting a robotics program into action, this guide presents suggestions in two areas: designing the learning environment and obtaining further resources. Information is provided about other robotics kits, besides LEGO Mindstorms, that can be used in early childhood. Finally, a list of references of scholarly work focusing on robotics and early childhood is presented.

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I am also thankful to Mitchel Resnick, who in his course "Technological Tools for Thinking and Learning," back in the 1990s at the MIT Media Lab, taught me by example what a constructionist learning environment looks like; and to Fred Martin, who helped me understand how robotics could be integrated into any object in our lives, including soft teddy bears and cozy bunnies like the ones I developed for my master's thesis at the Media Lab under the direction of Justine Cassell. I am also thankful to Sherry Turkle, who as a member of my doctoral thesis committee showed me the impact that technology can have in our understanding of our own psychology. Other people at the MIT Media Lab played a very important role in my learning about robotics and constructionism, and I am deeply thankful to them: Claudia Urrea, David Cavallo, Jacqueline Karaslanian, Edith Ackermann, Rick Borovoy, Amy Bruckman, Mike Best, Deb Roy, and members of the Epistemology and Learning Group and the Lifelong Kindergarten group.

In Argentina I am thankful to my mentors at Buenos Aires University, Alejandro Piscitelli and Anibal Ford, now colleagues and friends, who helped me grow intellectually and inspired me with their hard

academic work and sense of social responsibility when using technology. I am also deeply thankful to Rabbi Sergio Bergman and Lea Vainer, who in 1998 made it possible for me to work with families and young children to create robotic prayers in the Arlene Fern Community School. It was Rabbi Bergman who encouraged me to pursue the use of computers for teaching and learning about identity and human values.

At Tufts University, Chris Rogers, my colleague in the School of Engineering and Director of the Center for Educational Engineering Outreach (CEEO), played an important role in introducing me to the need for and challenges of bringing robotics into public schools. I am deeply thankful to Chris for supporting my work and for providing me with encouragement and resources to extend the work of the CEEO to early childhood. In addition, I thank him for carefully reading a complete draft of this book and providing me with feedback. At the CEEO I am deeply thankful to many people, in particular to Robert Rasmussen (whom I knew from his previous days at the LEGO Group) and to Kevin Staszowski and Merredith Portsmore, who have taught me so much about engineering education and young children.

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I am also thankful to Ioannis Miaoulis, now president and director of the Science Museum, who as Dean of Engineering at Tufts played an important role in developing the graduate program in Math, Science, Technology, and Engineering at Tufts University and had the vision to promote the hiring of interdisciplinary faculty such as myself. Thanks also go to Yvonne Spicer, Associate Director for K–12, National Center for Technological Literacy® (NCTL®) at the Museum of Science, Boston, for providing me with information on the current state of the art with respect to engineering and technology frameworks in the United States; to Christine Cunningham, now Vice President of Research at the Boston Museum of Science, for early but formative conversations about engineering education; and to Ken Berry and Natalie Rusk for providing me information about current robotics kits used in education. Many, many thanks go to my editor at Teachers College Press, Marie Ellen Larcada, for believing in this book project and helping me realize how much I have to contribute to the field of early childhood education.

Working on this book was possible thanks to the financial support provided by the Bernstein Award for Junior Faculty at Tufts University (I am deeply thankful to Jane and Leonard Bernstein); the CEEO faculty grant that allowed me to conduct a summer institute for early childhood educators where some of these ideas were piloted; and the National Science Foundation (NSF), award #0212046, “Multi-Threaded Instruction: Forming Multi-disciplinary Research Groups to Improve Undergraduate Education,” and NSF Career Award #IIS-0447166NSF, “Communities of Learning and Care: Multi-user Environments that Promote Positive Youth Development.”

Finally, I would like to thank my family from the bottom of my heart. My sincere thanks go to my mother, Lydia Umaschi, who had the vision to send me as a young girl in the late 1970s to participate

in a workshop to pilot some of the first versions of Logo in Argentina; to my mother-in-law, Nanny Bers, who read many versions of numerous papers on the topic to correct my English; to my husband, Josh Bers, whom I first met while we were both playing with robots at MIT and my English was not very good. Josh, with his calm manner, gives me love and support so I can both work and be a mom. I love you, Joshi! And I thank my three beautiful and playful children—Tali, Alan, and Nico—who participate in every open house of my courses and serve as guinea pigs for testing some of the projects created by my students. Most importantly, they are my best teachers about early childhood and they provide me with the inspiration to do this work.

I HOPE YOU WILL ENJOY reading this book as much as I enjoyed writing it. And I hope you become convinced, as I am, that by providing children early in life with powerful tools such as robotics, which are natural digital extensions of traditional learning manipulatives such as building blocks, we can help them develop readiness to become producers, and not only consumers, of technology. We can help them invent a better world for us and for the generations to come.

PART I

Constructionism: Technology and Early Childhood

FIGURE 4. Playing to learn and learning to play in a constructionist environment

We live in an advantageous time for introducing technology in early childhood. On one hand, given the increasing federal mandate to make early childhood programs more academically challenging, technology can provide a playful bridge to integrate academic demands with personally meaningful projects. On the other hand, discussions about the appropriateness of technology in early childhood are mostly put aside, and the pressing question is not "Should we introduce computers?" but "How should we introduce them?" (Clements & Sarama, 2003). The focus has shifted from technology to pedagogy.

This first Part of the book is about pedagogy. It presents a constructionist approach to using technology, in particular robotics, in early childhood. It describes four basic principles for developing successful early childhood constructionist learning environments that are developmentally appropriate:

1. Learning by designing meaningful projects to share in the community,
2. Using concrete objects to build and explore the world,
3. Identifying powerful ideas that are both personally and epistemologically significant, and
4. Engaging in self-reflection as part of the learning process.

The first chapter, on constructionism, is followed by a second chapter on sociocultural and developmental contexts needed for constructionism to flourish. Within this chapter, a section is devoted to exploring how the early development of technological fluency can happen hand in hand with socioemotional development. An interview with Dr. Rebecca S. New, an expert in child development and sociocultural theory, situates constructionism in the light of these theoretical contributions. At the end of Part I, two vignettes written by educators are presented to illustrate the use of robotics in early childhood classrooms.

CHAPTER 1

Constructionism as Developmentally Appropriate Practice

It would be particularly oxymoronic to convey the idea of constructionism through a definition since, after all, constructionism boils down to demanding that everything be understood by being constructed.

—Seymour Papert (1991, p. 2)

Constructionism might best be understood by educators trained in the Piagetian tradition as a constructivist approach to developing and evaluating educational programs that make use of technologies with the purpose of learning. Constructionism proposes that technologies, computers as well as tangible manipulatives such as robotics, are powerful for educational purposes when used for supporting the design, the construction, and the programming of personally and epistemologically meaningful projects (Papert, 1980; Resnick, Bruckman, & Martin, 1996a). Personally meaningful projects are those that we choose to work on because we are interested in them. Epistemologically meaningful projects are those that engage learners in exploring disciplinary realms of knowledge, as well as the nature of knowledge itself. These projects invite learners to encounter powerful ideas. This concept will be explored later in this chapter.

The notion of personally meaningful projects is not foreign to early childhood educators. Developmentally appropriate practice pays attention to the individual interests of the child as well as the community in which learning happens. In this context, learning environments should support children in their explorations, scaffold their learning, and provide interesting materials to manipulate and share with others.

In early childhood education there is general agreement about the efficacy of "learning by doing" and engaging in "project-based learning." Blocks have traditionally been used for this purpose. Constructionism suggests that computers can complement these already established practices by engaging children in "learning by designing" and "learning by programming." From a constructionist perspective, there is a continuum of learning opportunities that extends from blocks to robots. When the computational power is located not only on a screen but also on a tangible object, such as a mobile autonomous robot, we are encouraging children to explore projects that integrate bits and atoms, mechanics and electronics, which are present in our everyday lives.

The origins of constructionism can be traced back to the 1960s, when Seymour Papert, a mathematician and the director of the MIT Logo Group, based first at the Artificial Intelligence Laboratory at MIT and later at the MIT Media Laboratory in Cambridge, started talking about developing programming languages for children. At the time, given that computers were sophisticated and expensive machines occupying full rooms and requiring advanced mathematical skills to manipulate them, people laughed at Papert. However, he followed his vision. In 1967, the first version of Logo, a child-friendly version of the programming language LISP, also called the language of the turtle, was developed by Papert and a team from Bolt, Beranek and Newman (a high-technology research and development company), led by Wallace Feurzeig. Widespread use of Logo began with the advancement of personal computers during the late 1970s. Logo positioned itself as one of the first programming languages for children. Now, different versions of Logo exist, it has been translated into many languages, and it is widely used all over the world (Logo Computer Systems, 1999).

Technology, however, by itself is not enough to ensure good learning. Papert's colleagues and students used to joke, "Seymour doesn't come in the box." Although Logo was software carefully conceived to put children in the role of programmers, creators, discoverers, and producers of personally meaningful projects, it was not always used as intended. A top-down curriculum and an instructionist pedagogy could turn Logo into a completely different tool in classrooms where teachers did not understand the principles of constructionism. Pedagogy for how to use Logo was needed.

Papert's constructionism became widespread in education in 1980 with the publication of his pioneering book *Mindstorms: Children, Computers and Powerful Ideas* (Papert, 1980). In *Mindstorms,* Papert advocated providing children with an opportunity to become computer programmers as a way to learn about mathematics and, more importantly, to learn about learning. Although Papert, a mathematician, focused his research and Logo implementation in math education, he was convinced that the benefits of programming would extend far beyond Logo and mathematics. Through the process of designing and debugging computer programs, children would develop a metacognitive approach toward problem-solving and learning. Douglas Clements was a pioneer in conducting experimental studies in early childhood education to evaluate these assertions (Battista & Clements, 1986; Clements, 1987; Clements & Sarama, 1997).

Designing, building, and problem-solving can happen beyond the computer screen. Constructionism recognized at an early date the importance of objects for supporting the development of concrete ways of thinking and learning about abstract phenomena. This is consistent with early childhood education and its rich tradition of learning manipulatives. Thus, the original Logo had a robotic turtle, a creature that sat on the floor and could be directed to move around by typing commands at the computer. This first robotic turtle, based on a cybernetic British tortoise, became the predecessor of many of the LEGO-based robotics programming kits. In the mid-1980s Mitchel Resnick, Steve Ocko, and Fred Martin (Resnick, Ocko, & Papert, 1988), in Papert's lab at MIT, started to develop the first LEGO–Logo program. Part II of this book presents a history of this development and descriptions of commercially available robotics construction kits to use in early childhood.

Papert's constructionism is rooted in Piaget's constructivism, in which learning is best characterized as an individual cognitive process given a social and cultural context. However, whereas Piaget's theory was developed to explain how knowledge is constructed in our heads, Papert pays particular attention to the role of constructions in the world as a support for those in the head. Thus, constructionism is both a theory of learning and a strategy for education. It offers the framework for developing a technology-rich, design-based learning environment in which learning happens best when children and adults are engaged in learning by making, creating, programming, discovering, and designing their own "objects to think with" in a playful manner.

A constructionist learning environment gives children the freedom to explore natural interests using new technologies, with the support of a community of learners that can facilitate deeper understanding (Kafai & Resnick, 1996). There is a long-standing tradition of constructionist authoring tools and programming environments that follow the Logo steps (Resnick et al., 1996a). Some are explicitly designed for children's learning about mathematics (Abelson & DiSessa, 1981; Harel & Papert, 1990), about science (Wilensky, 1999; Resnick, Berg, & Eisenberg, 2000), about storytelling (Bers & Cassell, 1999), about language

(Bruckman, 2000), and about identity (Berman & Bruckman, 2001; Bers, 2001). Others extend the notion of stand-alone computer programming. These toolkits engage learners in the creation of virtual communities to foster peer learning and collaboration (Bruckman, 1998) and support them in establishing positive and caring connections and relationships (Bers, 2006).

Constructionism is a complex philosophy and approach that has evolved over time from its initial conceptualizations. The goal of this book is not to present a theoretical foundation of constructionism but to shed light over how constructionism informs developmentally appropriate practice when using technology in general, and robotics in particular. Thus, this book presents the ideas of constructionism organized by four basic tenets: (1) learning by design, (2) objects to think with, (3) powerful ideas, and (4) thinking about thinking. The next sections address each of these tenets.

Learning by Designing Within a Community

Constructionism proposes that people learn better when provided with opportunities to design, create, and build projects that are personally and epistemologically meaningful. Projects are designed based on personal interests and community needs. As in the Reggio Emilia approach to early childhood education, which was initiated by the Municipal Infant–Toddler Centers and Preschools of Reggio Emilia in Italy after World War II, projects done by children are shared with the community (Rinaldi, 1998). In constructionist settings this can happen in the format of an open house, demonstration day, exhibition, or competition. The goal is to provide authentic opportunities for children to share the process and products of their learning with others who are invested in their learning, such as family, friends, and community members.

Given that constructionism engages children in the design of an object—either a virtual creation on the screen, a printed document, or a robotic artifact—constructionist environments provide opportunities for celebrating and sharing the tangible products of learning. They are also structured to provide opportunities for personal interests and community needs to emerge. For example, depending on curriculum requirements or children's interests, teachers might choose a general open-ended theme, such as a circus, a robotic zoo, or a town, and invite children to develop their own projects within the theme. Another approach would be to set up a discussion about the needs of the children's school or community and brainstorm different ways of using technology to solve the problem. For example, children might decide they have a problem with squirrels that eat the bulbs they have planted in their school garden, and might decide to make a robot to scare them away (Bers, Ponte, Juelich, Viera, & Schenker, 2002).

Both approaches of structuring constructionist learning environments—theme-based and needs-based—provide learning opportunities for children to create and design technological projects following their own interests and ideas. Children might have wonderful ideas. However, their understanding of the technology and their skills might be limiting to the implementation of those ideas. How do we set up structures so ideas can become products? How do we prevent the frustration of children who conceive complicated projects that cannot be put to work?

These are important challenges in constructionist learning environments. Little children have big ideas. On the one hand, we want to help them follow their ideas, but we do not want them to become frustrated to the point they quit the work. On the other hand, we do not want their success to be scripted, too easy, or without failure. One of the approaches to finding this middle path is to help them understand and follow the design process. This is similar to what engineers or software developers do in their own work. They identify a problem. They do research to understand better the problem and to address it. They brainstorm different potential solutions and evaluate the pros and cons. They choose the best possible solution and plan in advance how to implement it. They create a prototype and they implement it. They test it and redesign it based on feedback. This happens over and over. Then, finally, they share their solutions with others. The cycle is repeated multiple times. This simplified version of the engineering design process can be found in the Massachusetts Engineering/Design frameworks (see Figure 5).

Providing children with a design journal and with many opportunities to talk about their ideas, and to discuss details of their implementation early in the process, is common practice in constructionist learning environments. As children work on their projects, many iterations and revisions will be done. Design journals make transparent to the children themselves, as well as to teachers and parents, their own

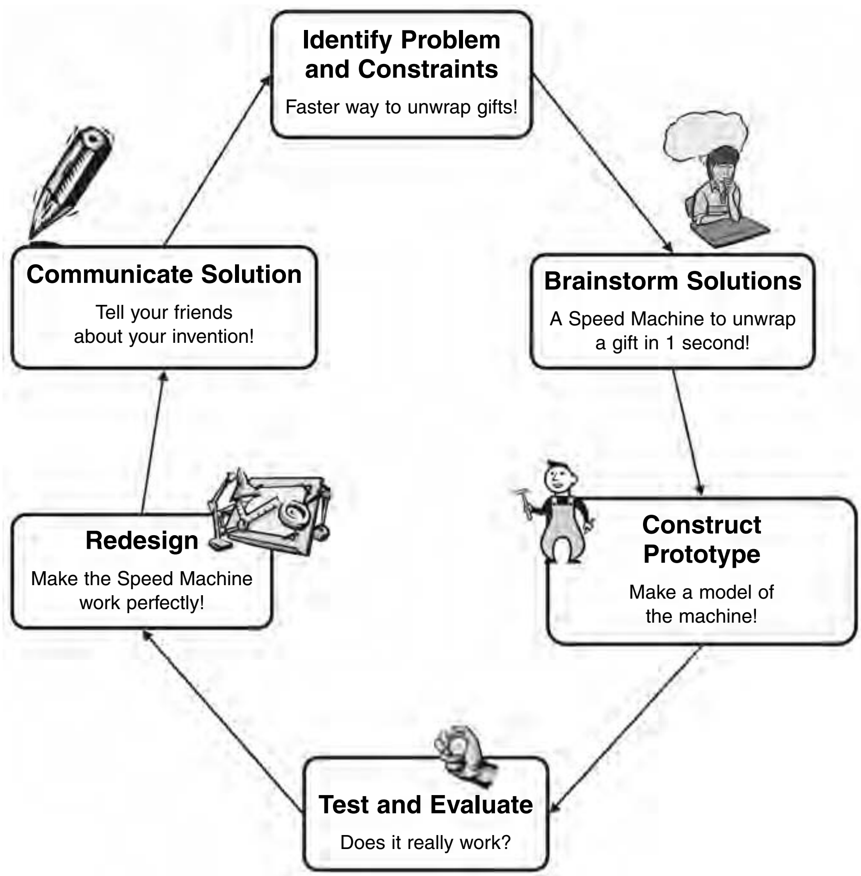


FIGURE 5. Simplified steps involved in the engineering design process, as appearing in the Massachusetts Engineering/Design Frameworks

thinking and the evolution of the project. More on this will be discussed later, in the section on thinking about thinking. Some children might choose to avoid using design journals or following a systematic design process. They do not like to plan in advance. They might belong to a group of learners that Papert and Turkle have characterized as tinkerers and bricoleurs (Turkle & Papert, 1992). They engage in dialogues and negotiations with the technology; their ideas happen as they design, build, and program. As Papert and Turkle wrote, "The bricoleur resembles the painter who stands back between brushstrokes, looks at the canvas, and only after this contemplation, decides what to do next" (Turkle & Papert, 1992, p. 169).

Constructionist learning environments allow for different epistemological styles, or ways of knowing, to flourish. Some children want and need constraints and top-down planning because they know what they want to make. Others enjoy working bottom-up and messing around with the materials to come up with ideas. Some methods of teaching robotics and programming, directly derived from engineering and computer sciences, provide structured paths for children to navigate the process from idea to product. For example, the formal steps of the engineering design process presented earlier are laid out in a design journal consisting of teacher-made worksheets. This approach might or might not work, depending on the child, the way the learning environment is set up, and the educational goals. In this book I advocate both pathways: design journals with a directive focus, in the form of questions (see Appendix C for an example), and design journals with lots of white pages, for those children who might want to invent their own strategies. Tinkerers and planners complement each other and can also learn from each other. Constructionist environments should be inviting and supportive to little engineers who thrive working with constraints and making advance plans, as well as to little tinkerers who create in dialogue with the materials.

Constructionism, like the Reggio approach, values the learning process as well as the products of learning. However, constructionism introduces a complex tension in our understanding of the learning process. A technological object—for example, a robotic car that follows the light or a Logo turtle that walks in the computer screen to make a square—either works the way it should, or it doesn't. But there are many different ways to make it work. How do we encourage a valuation in the process, if what counts is a properly working product? The secret is in structuring the constructionist learning environment to take advantage of what is not working properly. These are important "teachable moments" because they introduce the concept of debugging. Debugging, the methodical process of finding and resolving bugs, or defects and problems in a computer program, thus making it behave as expected, plays an important role in the culture of constructionism. Technology circles present a good opportunity for debugging as a community. A technology circle is a time for all, children and adults, to stop their work, put their projects on the table or floor, sit down in a circle together, and share the state of their projects. The teacher can start the technology circle by asking each child or group of children working together:

- What worked as expected and what didn't?
- What are you trying to accomplish?
- What do you think you need to know in order to make it happen?

The teacher uses children's projects and questions to highlight some of the powerful ideas illustrated by the projects. An emergent curriculum of what this particular classroom or learning community needs to know unfolds, based on authentic project needs. Before offering explanations and solutions, the teacher gives the opportunity for class members to provide responses. This is one of the most important parts of the process from a "what have they learned" point of view—but it takes substantial skill on the part of the teacher to do it right.

This approach to providing technical information on-demand, based on emerging needs, is an alternative to lecture-type introductions to the materials and skills needed. It also fosters a learning community, where peer interaction is supported and the development of different roles and forms of participation in the classroom culture is encouraged. For example, over time, there is always a child who is knowledgeable about mechanics, and thus tends to offer plausible solutions to classmates who are struggling with gears; there is a child who is very good at programming and is asked to consult on debugging; there is a child who can problem-solve when differences of opinion arise and is called on to resolve conflicts between group members. Although differentiation of roles is very important for growing a learning community, children should also be encouraged to take on new roles and to be flexible. It is sometimes easier for learners to succeed in what they are already good at, but they learn a lot more by succeeding in an area where they are weak.

Technology circles can be called as often as every 20 minutes at the beginning of a project, or only once at the end of a day of work, depending on the needs of the children and the need of the teacher to introduce new concepts. The challenging aspect of technology circles is that children might ask technical questions that the teacher is not well prepared to answer. This is an opportunity for modeling what learning with technology, and learning in general, is all about. The teacher can first disclose her or his lack of knowledge and say, "Well, I'm not sure. Let's try!" or can ask the children if someone knows the answer. If none of the above works, the teacher should then assure the children that she or he will find out by asking an expert or checking a Web site, and will bring back the answer next time.

Information-seeking, problem-solving, and learning how to find help and resources, are important activities in which workers in the information technology industry, and most professions, engage on a daily basis. Constructionist learning environments, and their emphasis on learning by designing, by creating, by programming, and by sharing with the community, provide opportunities for modeling useful lifelong learning habits.

Technological Tools for Learning: From Building Blocks to Robotics

Constructionism recognizes the importance of "objects to think with" and proposes new technologies, from software to robotics, as the new generation of learning manipulatives. The potential of using objects to think and learn with has a long-standing tradition in early childhood education. During the 1800s Montessori and Fröebel designed a number of "manipulatives" or "gifts" to help children develop a deeper understanding of mathematical concepts such as number, size, and shape (Brosterman, 1997). Today most early childhood educational settings have Cuisenaire rods, pattern blocks, DigiBlocks, and other manipulatives carefully designed to help children build and experiment. More recently, but in the same spirit, "digital manipulatives" developed by Mitchel Resnick and colleagues in the Lifelong Kindergarten Group at the MIT Media Laboratory (such as programmable building bricks and communicating beads) expand the range of concepts that children can explore (Resnick et al., 1998). For example, by embedding computational power in traditional children's toys such as blocks, beads, and balls, young children can learn about dynamic processes and "systems concepts," such as feedback and emergence, that were previously considered too advanced for them (Resnick et al., 2000).

It is within this tradition that robotics presents a wonderful opportunity to introduce children to the world of technology. Robotic manipulatives, such as the ones this book focuses on, enable children to use their hands and develop fine motor skills, as well as hand–eye coordination, and to engage in collaboration and teamwork. But they also provide a concrete and tangible way to understand abstract ideas. For example, by playing with mechanical parts to design their own robotic creatures, they explore levers, joints, and motors. The study of these simple machines becomes more concrete because children can build their own working machines. By adding gears to their machines, they explore the mathematical concept of ratio. By programming movement of these mechanical parts they start to explore the concepts of cause and effect, programming loops, and variables in a concrete and fun manner. By including sensors to detect input from the world, such as light or touch, they encounter the concept of feedback. All of these skills are fundamental stepping stones for understanding our complex world of bits and atoms.

The issue of abstract and concrete ideas is not new in education. It became prevalent with Piaget's view of children's intellectual growth as proceeding from the concrete operations stage to the more advanced stage of formal operations (Piaget, 1952). Furthermore, the emergence of the computer incited researchers, such as Sherry Turkle and Seymour Papert, to call for a "revaluation of the concrete" in education. In their breakthrough article in 1992, they identified how

> The computer stands betwixt and between the world of formal systems and physical things; it has the ability to make the abstract concrete. In the simplest case, an object moving on a computer screen might be defined by the most formal of rules and so be like a construct in pure mathematics; but at the same time it is visible, almost tangible, and allows a sense of direct manipulation that only the encultured mathematician can feel in traditional formal systems. (Turkle & Papert, 1992, p. 162)

Turkle and Papert (1992) were describing the manipulation of virtual objects in the screen, but the same process happens, and becomes even more powerful, when children are provided with objects that are physically tangible as well as digitally manipulable, such as robotic manipulatives. Furthermore, the physical characteristics of these "concrete" objects foster the development of sensorimotor skills that, in early childhood, are as important as intellectual ability.

However, using a concrete object to learn important ideas does not guarantee that the ideas will become concrete for the child (Clements, 1999). Wilensky (1991) proposes that "concreteness is not a property of an object but rather a property of a person's relationship to an object." Therefore, "concepts that were hopelessly abstract at one time can become concrete for us if we get into the 'right relationship' with them." According to Wilensky, the more relationships we can establish with an object, the more concrete it will become.

Robotic manipulatives, used in a constructionist learning environment in which children can design personally meaningful projects, allow for establishing many connections. Some children might connect with the materials as little engineers, deeply interested in the mechanisms. For example, by building with gears and motors they are likely to encounter powerful ideas such as ratio. These ideas will be studied later on, as schooling progresses, in a more abstract form, but the first personal connections will already have been established. For example, in the Foreword to his book *Mindstorms,* Seymour Papert talks about how playing with gears in his childhood fueled his later passion for mathematics. Other children might connect as little storytellers and make robotic creatures that enact a play, more interested in the meaning of the project they are creating than in its inner workings. For example, a little girl in Argentina was very busy building a theater in which two robotic puppets would become friends again after a fight. Thus, she needed the puppets to shake hands, a difficult robotic movement to coordinate. She was not interested in the technology itself. But she kept going until she made it work, just the way she wanted it, because it was important for her to create a project about friendship (Bers & Urrea, 2000).

Powerful Ideas and Wonderful Ideas

Papert's 1980s pioneering book was called *Mindstorms: Children, Computers and Powerful Ideas*. This last phrase, "powerful ideas," is one of the most complex concepts to understand within constructionism. Over the years, a growing community of researchers and educators have used the term *powerful ideas* to refer to a set of intellectual tools worth learning, as decided by a community of experts in each of the fields of study. However, different people have used the term in diverse ways, and among the powerful ideas community there are divergent opinions about the benefits and dangers of presenting a unified definition (Papert & Resnick, 1996).

In this book, I propose a conceptualization of the term based on Papert's claim that powerful ideas afford new ways of thinking, new ways of putting knowledge to use, and new ways of making personal and epistemological connections with other domains of knowledge (Papert, 2000). Powerful ideas can be (1) content-specific, expressed as "knowing-that" or propositional knowledge with a discipline as a birthplace: for example, the concept of zero; (2) process-specific, cutting across different subjects and domains, and often expressed as "knowing-how" or procedural knowledge, such as how to multiply by zero; their birthplace is a skill or a set of strategies for doing something, for example, problem-solving or addition; or (3) a combination of both, "content–process" powerful ideas. For example, technological fluency is a powerful idea of the "content–process" kind. Technological fluency refers to the ability to use and apply technology in a fluent way effortlessly and smoothly, as one does with language (process), but also involves the development of knowledge within the information technology domain (content). The powerful idea of technological fluency is central to constructionism and will be explored later in this book.

Constructionism asserts that new technologies can become liberators or incubators of powerful ideas. For example, some powerful ideas existed before the computer, but the computer liberated them by making them more powerful and accessible to a wide range of people. Papert (2000) uses modeling as an example of a powerful idea that was always in the culture but, with the appearance of computers, was elevated. Scientists as well as children could start making their own models of complex phenomena and understanding them in new ways. Resnick (1994) uses decentralized systems, such as the behaviors of ant colonies and bird flocks, as an example of an idea that before computers was very hard for children to grasp. Computers did not originate decentralized systems, but they did provide good ways of thinking about them. Other ideas stemming from computers are, for example, technological fluency and debugging.

Constructionists envision the computer as a powerful carrier of new ideas and as an agent of educational change. Although school reform is a complex topic, constructionism adds to this dialogue by proposing the introduction of computers into the classroom as a way to restructure learning. Instead of facts or skills, powerful ideas can be addressed. The question would shift from "How do we develop child-centered, framework-based curriculum?" to "How do we nurture a learning environment built on powerful ideas?" The role of computers is to empower children and teachers to develop and understand powerful ideas.

The importance attributed by Papert and colleagues to the world of ideas derives from the Piagetian legacy concerned with epistemology: understanding how we know what we know, how we construct knowledge. Educational researchers such as Eleanor Duckworth (1991), from Harvard University, propose a similar concept: wonderful ideas. According to Duckworth, wonderful ideas are personal insights or revelations. Ideas can be wonderful for someone because they provide a basis for thinking about new things and questions to ask, but they may not necessarily look wonderful to the outside world. Following a Piagetian tradition, in Duckworth's vision, wonderful ideas are deeply connected with the developmental stage of the individual and with stepping onto a new stage. Wonderful ideas are results of an individual's previous knowledge combining with intellectual alertness to ask new questions and play with materials in new ways.

Although powerful and wonderful ideas have many things in common, they stress slightly different dimensions of learning. Whereas Duckworth's wonderful ideas refer to the developmental process of an individual, Papert's powerful ideas take a more cultural perspective. Certain ideas are powerful, from an epistemological perspective, and children should be given the chance to explore them. Thus, computers take on a role to help them to encounter them. Once upon a time, all the powerful ideas were wonderful ideas grounded in personal excitement and confidence to experiment. But all wonderful ideas will not become powerful ideas. Powerful ideas are wonderful ideas that stand the test of time and that are successful in the marketplace of ideas. A powerful idea needs to establish five types of connections: cultural, personal, domain, epistemological, and historical.

- *Cultural connections.* An idea must be already established in a culture before it can become powerful. It becomes powerful when the culture reaches consensus about its importance and relevance for the culture itself. At the same time, once installed in society, a powerful idea naturalizes itself and appears as if it was always there, it is taken for granted, and its power is not questioned (Barthes, 1972). For example, in a country like the United States, democracy is a powerful idea so grounded in the culture that many would not even recognize it as such. But in other countries, with recent histories of military dictatorships, democracy is not normalized. In the descriptions of the four other types of connections needed for an idea to become powerful, I will use democracy as an example to ground the theory.
- *Personal connections.* Powerful ideas evoke an emotional response in people because people can make connections between the powerful idea and their interests, passions, and experiences. People need to get to know and establish personal relationships with the ideas, in a way similar to how they get to know and establish relationships with other people. People who have experienced life in a democratic country tend to like democracy and couldn't bear to live in any other way.

- *Domain connections.* Powerful ideas serve as organizing principles for rethinking a whole domain of knowledge and connecting it with others. A domain defines specialty areas of knowledge where many diverse subjects or topics come together. For example, young children might be interested in the domain of animals, and this domain can be used to teach them about different subjects such as biology and geography. The powerful idea of democracy can serve to organize the domain of public life, and at the same time it connects to other domains such as human rights. Democracy becomes a powerful idea when people know facts such as rules that organize a democratic society and when they can connect their own situation with cases of democratic experiences. It also becomes a powerful idea when people can apply skills, such as voting, and mental processes, such as conflict resolution.
- *Epistemological connections.* Powerful ideas open up new ways of thinking, not only about a particular domain, but about thinking itself. Powerful ideas serve to make a connection with the "meta" level. To be powerful, an idea needs to reflect back on our own way of constructing knowledge about the world and ourselves. For example, democracy opens up a new way of thinking about fair organization and distribution of power. This new way of thinking applies to different domains as well as reflects back into our own way of living, thinking, and learning.
- *Historical connections.* Powerful ideas persist over time and have a very broad range of influence. They are not only a matter of fashion; their influence can be felt by many generations and can change the intellectual atmosphere of an historical period. For example, in France prior to the Revolution, democracy was not a powerful idea; it was hardly an idea at all. However, once it became powerful it had a multiplier effect, influenced the world, and persisted over the centuries.

These five dimensions of powerful ideas contribute to making the understanding of the concept difficult. Seymour Papert sometimes laments that, over the years, readers of *Mindstorms: Children, Computers and Powerful Ideas* have focused so much on the word "computers" in the title and have forgotten about "powerful ideas." The power of computers for education lies in their potential to assist children in encountering powerful ideas and to engage them in experimenting with and testing these ideas.

Early childhood education has paid particular attention to one dimension of powerful ideas: personal connections. There is agreement about the need to leverage children's own intuitions and passions. Emergent curriculum builds upon children's interests and is responsive to the ideas, excitement, and questions from the children themselves (Rinaldi, 1998). National Association for the Education of Young Children (NAEYC) guidelines for promoting integrated curricula are very close in spirit to the constructionist notion of powerful ideas. These guidelines call for powerful principles or concepts applied generatively across disciplines (i.e., principles that support the development of new ideas and concepts) and emerging from and connecting to children's personal interests (Bredekamp & Rosegrant, 1995). What is new for early childhood education is the emphasis on epistemology. Constructionism invites us to revisit the ideas we are helping our children learn through the looking glass of the five dimensions of powerful ideas.

Learning About Learning with Technology

In constructionist learning environments self-reflection and "thinking about thinking" play a very important role. Papert and colleagues (Papert, 1980; Harel & Papert, 1991) suggest that the best learning experiences occur when individuals are encouraged to explore their own thinking process and their intellectual and emotional relationship to knowledge, as well as the personal history that affects their learning experience.

For example, every semester for the last 6 years I have been asking my students, early childhood preservice teachers, to come up with examples of powerful ideas they encountered as children and continued to explore as grown-ups. To my amazement, every single time, they have difficulties recalling and talking about ideas. They remember they learned about polar bears and bats (although they are not sure what about them they learned), but they are not able to remember (probably because no one helped them make the connection) that some of the powerful ideas behind studying those animals were the concepts of habitat and adaptation. This exercise in self-reflection tends to open their eyes to the importance of not only teaching but also engaging children in reflection about the *why* behind what they are taught.

Self-reflective practice has acquired a predominant role in early childhood education with an emphasis on documentation via the Reggio approach. Documentation allows "the construction of traces (through notes, slides, videos, and so on) that not only testify to the children's learning paths and processes, but also make them possible because they are visible" (Rinaldi, 2001, p. 83).

Although computers can aid in the process of documentation by providing opportunities to develop digital portfolios, edited videos, photo books, and audio books, constructionism views the computer—in particular the ability to program the computer or a robotic creature—as a powerful means of gaining new insights into how the mind works and learns. Thus, computers are not only a tool for documentation but also a vehicle for thinking about thinking. Not surprisingly, researchers in artificial intelligence, who are fascinated with the question of how to make machines that think, write some of the most interesting philosophical essays about self and identity. Some examples are the work of Joseph Weizenbaum (1976), Marvin Minsky (1986), and Terry Winograd (Winograd & Flores, 1987).

Computers can make both learning and thinking visible. For example, the early work of Sherry Turkle explores how young children become philosophers when trying to make sense of how a computer toy works and thinks. Ultimately, children must grapple with how to distinguish what is alive from what is not alive (Turkle, 1984). Developmental psychologist Edith Ackermann (1991) studied young children's notions of control elicited by robots and other technologies.

Within the constructionist tradition, self-reflection and understanding of how knowledge is being constructed are not only goals for the teacher but also for the learner. This is an important shift from the Reggio approach, in which documentation is mostly conceived from a teacher's perspective (Malaguzzi, 1998). The Reggio approach provides teachers with a basis for modification and adjustment of teaching strategies, with a means for relationship building with different stakeholders in the educational process, with new ways of assessing children's learning, and with a tool for reflection about the teaching and learning process (Helm, Beneke, & Steinheimer, 1998).

Constructionism has paid more attention to learning than to teaching. Therefore, the tools of documentation should be put in the hands of children, who can assume responsibility for documenting their own learning process. For this purpose, the emphasis is on using design journals, pinups, and open houses in constructionist experiences. By sharing with others our own learning experiences, we start to make sense of our personal process of constructing knowledge. Public displays of the learning process and its products for members of the community, as discussed in the section "Learning by Designing Within a Community," serve a dual function: to make learning visible to others and, most importantly, to ourselves.

This chapter has explored the history and philosophy of constructionism as it relates to early childhood education. Four basic pillars have been identified as being particularly informative for our work with young children and technology: (1) the development of learning environments that encourage children to become designers of their own projects to share with a community, (2) the use of technological objects, in the tradition of early childhood learning manipulatives, for making abstract concepts more concrete, (3) the understanding of powerful ideas as the building blocks of curriculum and of computers as carriers of powerful ideas; and (4) the importance of self-reflection about our own learning process through documentation and communication.

NOW THAT WE HAVE an understanding of constructionism as a pedagogy that informs the use of technology in early childhood, the next chapter will focus on how constructionist learning environments should promote socioemotional as well as cognitive development. It will also address how different supports need to be put in place for creating developmentally appropriate, technology-based learning environments that put children in the role of designers, programmers, and builders of their own personally and epistemologically meaningful projects.

CHAPTER 2

Socioemotional and Developmental Contexts for Learning with Robotics

We have sought out the subjective computer. Computers don't just do things for us, they do things to us, including to our ways of thinking about ourselves and other people.

—Sherry Turkle (1995, p. 22)

The use of robotics has traditionally been associated with math and science education. However, in early childhood education, technology cannot be used solely with the goal of breeding little engineers, little mathematicians, and little scientists. Early childhood is not a time for specialization but a time for helping children develop holistically. Emotional and social growth is as important as cognitive development.

This chapter explores how such growth can be facilitated. It introduces the concept of positive technological development (PTD) as a learning trajectory that starts in early childhood and that leads in the direction of improving our own lives and the lives of others in the community through the use of technology (Bers, 2007a). While developing technological fluency is important for understanding the world of bits and atoms around us, it is just as important to provide children with the vision that technology can also be used to make a better world. That, in a nutshell, is the concept of PTD.

No educational experience happens in a vacuum. There are social and cultural contexts that make the work successful, and even possible. One context is institutional, and this chapter will focus on two different approaches that schools, child care centers, or family day care can use for introducing technology in the classroom: the technocentric and the systemic. The other context is the family. The chapter will conclude with a discussion of the role of families in promoting the use of technology in positive ways and in supporting the work of schools.

The Big Picture: Promoting Positive Technological Development

Over the years, practitioners and researchers in educational technologies conceived of two different ways of how children should learn with and about technology: computer literacy and technological fluency. Both approaches address the questions of what it means to be able to successfully use technology in today's world, and how to best approach teaching and learning with and about technology.

Whereas computer literacy relies heavily on developing instrumental skills, technological fluency focuses on enabling individuals to express themselves creatively with technology. In Part II, Chapter 3, in the section titled "Teaching and Learning Powerful Ideas with a Robotic Manipulative," these approaches will be explored further. For now, we need to understand that technological fluency, which is strongly linked to constructionism, emphasizes that in the process of being creative with technology, children are also likely to develop new ways of thinking. For this reason, the computer's role goes far beyond being an instrumental machine. Psychoanalyst and MIT professor Sherry Turkle's pioneering work recognizes that computers can serve psychological functions by enabling children to explore who they are (Turkle, 1984) and how they relate to others when participating in Internet-based activities (Turkle, 1995).

This recognition of the role of computers sets the stage for positive technological development. It invites educators and practitioners who are using or will use educational technologies to explore the positive role that computers and robotics can play in the socioemotional development of young children. It encourages them to pose questions such as: How can we use technology to help children think about the self in different ways? How can we design technologically rich learning environments that will allow children to explore their own psychology and their social relations? How can we develop curricula that integrate the use of technology with socioemotional development?

Technology has an impact on children's personal, social, and emotional lives from a very early age. In today's world, children need more than computer literacy and technological fluency to use technology in positive ways. Developing competence and confidence regarding computer use is a necessary step. It is also important to develop character traits that will help children use technology safely to communicate and connect with others, and to provide them with opportunities to envision a better world through the use of computers. Although in early childhood, children are not yet avid unsupervised users of the Internet, it is during this time that attitudes and ways of thinking are starting to form that will shape their adolescence. Positive technological development, as an extension of computer literacy and technological fluency, adds a psychosocial component to the possibilities of technology-rich programs to promote learning.

Like Erik Erikson (1950), developmentalists ask the question "What is the job or task of an individual at different times in his or her development?" In this spirit I encourage everyone, teachers in particular, to ask, "What is the job of a child growing up in a technologically rich period such as ours?" Computers are in children's lives, and are used differently throughout the developmental span. Children first use them at home for playing educational games, in the best cases, and for babysitting, in the worst. Later, they use technology at school for many different purposes, from writing assignments to Internet research. As they grow, children use technology to communicate with friends, to listen to and exchange music, to meet new people, to share stories with relatives, to organize civic protests, to shop for clothing, to engage in e-mail therapy, and to date (Subrahmanyam, Greenfield, Kraut, & Gross, 2001; Bers, in press).

Technology permeates children's lives. It is not limited just to school. As technologies evolve, they become a part of early childhood, a time in which a sense of self and one's role in the world is starting to develop. As educators it is our responsibility to lay a foundation for children to use technology not only to grow into better mathematicians, scientists, or engineers, but also to contribute in positive ways to themselves, their communities, and the world. That is positive technological development.

Positive technological development complements a learning trajectory initiated by computer literacy and technological fluency, which focus on cognitive development, by adding a socioemotional dimension. From a theoretical perspective, positive technological development grows out of the foundations of constructionism (with its emphasis on computational tools that provide opportunities for learning through making, designing, and programming) and applied developmental science (with its focus on understanding positive youth development).

Applied developmental scientists identify six assets or characteristics of thriving individuals, which they refer as the "six C's": competence, confidence, caring, connection, character, and contribution (Lerner et al., 2005). Taken together, these characteristics reflect a growing consensus about what is involved in healthy and positive development among people in the first two decades of their lives.

Building on this work, educational programs that make use of technologies from a framework of positive technological development should help young children develop (1) *competence* in intellectual endeavors and the acquisition of computer literacy and technological fluency; (2) *confidence* in their own learning potential through technology and their own ability to solve technical problems; (3) *caring* about others expressed by using technology to engage in collaboration and to help each other when needed; (4) *connection* with peers or adults to use technologies to form face-to-face or virtual communities and social support networks; (5) *character* to become aware of their own personal values, be respectful of other people's values, and assume a responsible use of technology; and (6) *contribution* by conceiving positive ways of using technology to make a better learning environment, community, and society.

These six C's can guide educators in creating technologically rich learning environments, from curriculum development to assessment, regardless of the particular powerful ideas in the curriculum. Part II of the book addresses some of the possibilities that robotics offers for exploring powerful ideas from different disciplinary contexts. This section focuses on how to design programs that also promote positive technological development.

How do we develop these programs? How do we know if the technologies we are using support positive technological development or are limiting in that they are only designed for teaching a particular concept or powerful idea? How do we design curricula that take into consideration positive technological development when integrating technology with disciplinary knowledge? These are legitimate questions. It is hard enough to develop an early childhood curriculum that integrates math and science with computers. It is even harder to address socioemotional aspects through the use of technology. However, as early childhood educators we are obligated to take on the challenge. A genuine concern for socioemotional growth is mandatory in developmentally appropriate practice. Thus, technology needs to be integrated with this purpose as well.

The positive technological development framework helps us to address this challenge by proposing: (1) the concept of identity construction environments; (2) questions that as educators we should ask ourselves; and (3) the "six C's by six C's" model to orient our choice of technology, curriculum development, and assessment strategies.

Identity Construction Environments

Identity construction environments are explicitly designed to promote positive technological development. There are two types: tool-centric and environment-centric. Identity construction environments can be *technological tools* purposefully designed for supporting the exploration of self and community. For example, the Zora virtual world encourages children to explore their personal and moral values while creating and inhabiting a virtual city (Bers, 2001). Or they can be *technologically rich environments* in which existing technologies, initially developed with other goals, are used with a positive development framework.

Both types of identity construction environments, tool-centric and environment-centric, are designed according to 10 principles:

1. Provide a safe space in which children can design and program personally meaningful projects that highlight and make accessible concepts and ways of thinking about identity and values.
2. Support young users to engage in self-reflection and introspection.
3. Provide opportunities to engage in interactive design-based activities to learn about self and community by becoming technologically fluent.
4. Provide tools with which users can create a complex representation of the self, highlighting its multiplicity of aspects and its change over time.
5. Provide flexibility to express and explore powerful ideas about identity in different ways (e.g., writing a story, drawing a picture, programming an interactive character, conversing with others, etc.).
6. Provide opportunities for children to engage in narrative expression, particularly in telling stories about the self.
7. Engage and motivate users for long periods in a natural and self-initiated way.
8. Make use of networked technologies to create a community to put to the test new concepts and ways of thinking and behaving.
9. Support the passage from knowledge to action. Namely, provide opportunities for learners to express their identity as well as to explore it through behaviors in the context of a community of practice.
10. Be designed following a participatory method in which potential users, both professionals and children, become partners in the different stages of the design process.

Whereas a small subset of technologies can be identified as identity construction environments (very few computational tools are specifically designed to promote positive development), most constructionist technologies can become identity construction environments if the design of the curriculum and the learning environment augment and supplement what the technology can offer. For example, children can use robotics to build, to create, and to program their own projects, thus meeting the design specifications of identity construction environments in principles 3, 4, 6, 7, and 10 of the list. The other elements, which are about the development of a community and a safe space to support learning and reflection, are not inherent to the robotics technology. However, they can be addressed by a learning environment and a curriculum developed with the goal of promoting positive youth development. This leads to the questions that, as educators, we need to ask ourselves.

Questions

The first question we need to ask is: What kind of technologies are we using to promote positive technological development? Can they be described as "identity construction environments," technologies purposefully designed to encourage children to explore issues of self and community? If the answer is "yes," we know that there is a good match between our teaching and learning goals, at least with respect to positive technological development and the technology of choice. If the answer is "no," we need to know if the technology is flexible enough that it could be incorporated into a constructionist learning environment with a curriculum based on the positive technological development approach. Robotics technology is an example of this second category. The technology by itself was not designed to promote explorations of self and community, but as a means of learning about engineering, math, and science. However, the constructionist nature of the robotics kits, which enable children to create open-ended projects, can be easily integrated into a learning environment that promotes positive technological development. For example, in Project Inter-Actions, children and their parents were invited to create robotics projects to explore an aspect of their cultural heritage (Bers, New, & Boudreau, 2004; Beals & Bers, 2006). Part II of this book will provide more examples of such activities.

If we have found a technology that is flexible and can be used in a constructionist way to engage children in the design, making, and programming of their own projects, then we need to understand how we can integrate that technology into a developmental technology framework. How do we create identity construction environments? The 10 guidelines presented earlier are a good start. But the "six C's by six C's" theoretical model (see Figure 6) provides a foundation by showing how each of the six desired positive assets or characteristics of an individual can be promoted by specific design features in the technology, the curriculum, and the learning environment that engage children on different behaviors: (1) *content creation* to promote *competence* in the use of technology; (2) *creativity* to foster *confidence* in children's own uses of technology to make meaningful projects; (3) *communication* in both synchronous and asynchronous ways to support the formation of networks of *caring*; (4) *collaboration* that enables *connection* between people; (5) *conduct* to engage in ethically and morally responsible actions guided by *character* traits; and (6) *community-building* to design and participate in environments where one can make positive *contributions*.

Following the conceptual foundation laid by the positive technological development framework, I will next focus on how robotics, a technology traditionally used for cognitive development, can be used to support socioemotional development.

Promoting Socioemotional Development Through Robotics

This chapter focuses on how robotics can be used to nurture the social and emotional aspects that are so important in early childhood, and that most work with educational technology tends to ignore. Some work on computers and early childhood education has shown that computer programs can engage children in social interactions (Wang & Ching, 2003). For example, research has shown that contrary to the view that using computers isolates young children, children at the computer spent nine times as much time talking to peers while on the computer as while doing puzzles (Muller & Perlmutter, 1985). Based on this foundation, what about robotics?

When robotics is used in the context of constructionist learning environments to promote positive technological development, two elements become important: teamwork and the management of frustration. In this section I use teamwork as an example of how to support social development, and I use the management of frustration as an example of how to support emotional development.

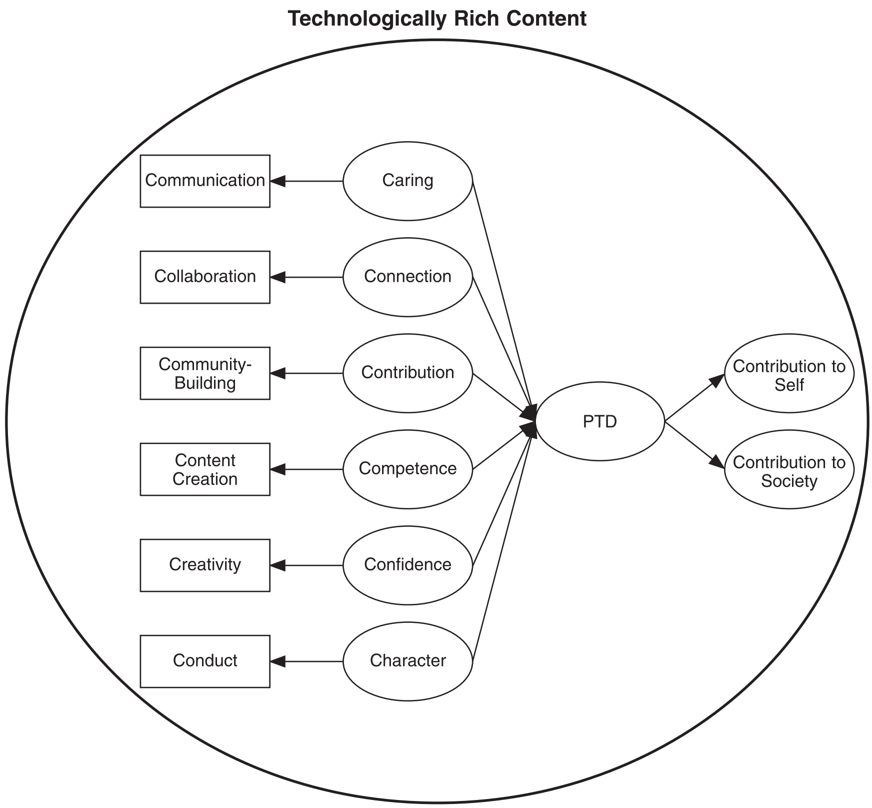


FIGURE 6. The "six C's by six C's" model of positive technological development

Teamwork is about collaboration and cooperation. It is about differentiation of roles and working together toward a common, shared goal. A child who is able to work well in a team will more likely have better learning experiences in school and better job options in adulthood. As described in Chapter 1, in constructionist learning environments children can choose to work on a technological project to address a shared interest or a shared need. Both the interest-based and the needs-based models offer opportunities for each child to express his or her individuality, while at the same time coming together in a bigger project.

Robotics provides a platform for engaging children in a joint project based on individual interests. But it can also encourage teamwork by requiring the integration of multiple skills held by different children (programming, engineering, building, etc.). Although participating in teamwork promotes the development of all six characteristics in the positive technological development framework, two of the C's play a most salient role: caring and connection. Children who work in groups to create a robotics project are not only mastering the technology, they are also learning to negotiate whose ideas will be implemented and how, while assuming a caring stance toward each other and learning how to connect with each other by asking for feedback and help.

A learning environment that supports children's development of a sense of caring and connection is designed to encourage communication and collaboration. Our choice of how to present the materials to the children can be a vehicle for promoting this. For example, if LEGO building pieces are situated in bins in the center of the room sorted by types of pieces (instead of giving an already sorted kit to each child or group), children will be learning how to take what they need without depleting the bins because someone else might need a piece. They will also learn to negotiate for the "most wanted" pieces, such as special sensors or the colorful LEGO minifigures.

When learning with robotics, managing the social relations that make possible the creation of complex projects is as important as managing our own emotions. Over the years I have often observed a sense of frustration because the technology is not doing exactly what we (teachers and children) hope it will do and because we cannot build the complex mechanic structure we had in mind. Although this frustration tends to be greater in the adults than in the children, who approach learning in a playful manner, it is important to address it instead of ignoring it. Technology works or it doesn't work. It is in our face. And it can be very frustrating to realize that, after many tries, the jaw of the crocodile doesn't open the way we want it to open, or the robotic car breaks every time it turns to the left. How do we help children manage frustration?

Some teachers want to avoid children's frustration and therefore carefully choose projects that will shield their children and provide step-by-step directions so children do not encounter pitfalls. This way of working is not consistent with the constructionist approach that I am presenting in this book. It deprives children of the authenticity of the learning experience and of the pleasures of learning by discovering.

Learning is hard. Alan Kay, pioneer in the development of the personal computer, refers to this as "hard fun," an activity that engages us because it is enjoyable but at the same time is challenging. Constructionist learning environments provide children with opportunities to have "hard fun," but should also provide ways to support the management of frustration. Some teachers set up the environment in such a way as to create a culture in which succeeding the first time is seeing as a rarity and as a sign that the child did not push him or herself that hard. "It worked on your first try, do you think you could try something a little bit more challenging? How about having a car that moves on its own with a motor, instead of a car that moves because you push it?" Other teachers always remind students that a project will break a hundred times before it works, thus anticipating the inevitable. This helps to create a safe learning environment in which it is acceptable to have things not working, breaking, and falling apart. It happens to everyone. Having fun and setting up an environment in which laughter is commonly heard is one of the best ways to help children manage their frustration when working with technology. Researchers at the Center for Educational Engineering Outreach at Tufts University have also found that if they only engage children in one or two robotics projects during the academic year, children tend to have difficulty with failure—but if they are presented with weekly opportunities to develop their projects, they learn how to learn from their failures.

Learning how to manage our frustration is associated with the development of the C of confidence when using the vocabulary of positive technological development. If we help children learn how to react when things do not work as expected, we are also helping them to become sure of themselves—confident in their ability to find a way out, either by trying multiple times, by using different strategies, or by asking for help. We are showing them that even though things might be very frustrating, we do not give up. We take an alternative path. This is an important aspect of emotional development.

Technology in the Classroom: Technocentric vs. Systemic Approaches

In Chapter 1 we learned about constructionism as a theory to guide the use of technology in a developmentally appropriate way. Then, we focused on how technology can be used to promote positive technological development. Within this context, we explored how to design technology-rich learning environments that support children's emotional and social development. However, none of the above is possible if we do not take a step back and, before introducing technology into the classroom, develop and examine our approach. Do we take a technocentric stance and understand technology as a central player in the learning environment? Or do we take a systemic approach and understand technology as one more component of a learning culture?

A technocentric approach primarily focuses on the new technology and is concerned with equipping the classroom or school with hardware and software. The budget is increased to buy new computers, and discourse centers on the new acquisitions. Seymour Papert (1987) coined the term "technocentric thinking" to capture an analogy with the egocentric stage in Piaget's developmental model of the young child. Although Piaget's egocentrism is not about the selfishness of the child, but about his or her inability to understand anything independently of the self, technocentrism refers to the tendency to give a similar centrality to technology.

Technocentric thinking is very popular among educators. Papert alerts us:

> One might imagine that "technologists" would be most likely to fall into the technocentric trap and that "humanists" would have a better understanding of the role of culture. . . . But things are not so simple. People from the humanities are often the most vulnerable to the technocentric trap. Insecurity sometimes makes a technical object loom too large in their thinking. Particularly in the case of computers, their intimidation and limited technical understanding often blind them to the fact that what they see as a property of "the computer" is often a cultural construct. (Papert, 1987, p. 25)

A technocentric approach is revealed through questions such as "What is the effect of the computer on cognitive development?" or "Does robotics work in early childhood?" The ways these questions are posed shows a tendency to see technology as the agent of change in the learning environment. However, such a context cannot change because of the sole introduction of the computer; the pedagogical approach and the people in charge of teaching and learning are more important.

A systemic approach, in contrast to a technocentric one, is concerned with the learning culture. This approach gives equal or greater importance to the training and support that teachers receive as well as to the pedagogy with which the technology is used. The budget grows or is reallocated to support professional development and the hiring of a technology coordinator for the school. Teachers are provided with opportunities to discuss how to integrate technology in their curriculum. In the process of revisiting some of the fundamental assumptions about teaching and learning, technology might play an important role as a catalyst of new dialogues. A systemic approach is revealed through questions such as "What do we need to make happen in the school so the technology can add to our teaching?" or "How can we revise our curriculum so the technology can be better integrated?"

Constructionism presents a tension between the importance of technology to support children's construction of knowledge and the dangers of "technocentric thinking." On the one hand, constructionism states that not all tools are made equal, and some are more conducive than others to helping children construct knowledge about the world. For example, tools such as Logo and the LEGO Mindstorms kit engage children in the design and programming of personally meaningful objects. Thus, there is an effort in the constructionist community to design a variety of computational construction kits (Resnick et al., 1996a). On the other hand, constructionism warns us against placing the tools at the center of educational change or viewing them as responsible for certain educational effects or learning outcomes.

This tension is a healthy one. It reminds us that both the technocentric approach and the systemic approach need to be examined and understood in order to successfully use technology in the classroom. It is my firm belief that before introducing computers or robotics to our children (or to our teachers, if we are in an administrative role), we should give some serious thought to where we stand in the continuum between technocentric and systemic approaches. This has implications for the kind of culture of learning we will be developing, the kind of discourse we will be using (among educators, as well as among the wider learning community such as parents), the efforts we will be putting toward developing assessment methods that are consistent with our approach, and the decision-making regarding budget, time, and resource allocation.

The Role of the Family: Lessons from Literacy

As shown earlier, the context of the learning environment in which technology is introduced is as important, or even more important, than the technology itself. The previous section explored the institutional context by focusing on two different approaches that schools, child care centers, or family day care homes can use for introducing technology: the technocentric and the systemic. This section explores the family context.

The educational technology community has much to learn from the family literacy movement. This growing movement in the United States and abroad emphasizes involving parents in the early years (Goodling Institute for Research on Family Literacy, 2006; National Literacy Trust, 2007). For example, research has shown that the practice of parents reading with their young children is a significant contributor to young children's learning to read (Teale, 1984; Senechal & LeFevre, 2002). As children grow, research shows that the stronger the home–school connection through parental involvement, the higher the likelihood of ensuring educational success (Fan & Chen, 2001).

In the 1960s most of the literacy intervention programs followed the "parent impact model" in which a teacher visited homes and presented pedagogy and materials to the parents. Although this model proved to be successful, critics maintained that this was a deficit model, assuming that parents lacked basic skills and methods for teaching. Later on, the success of parental involvement in Head Start led to the creation of the Parent Education Fellow programs, which promoted diverse parental participation. The goal was for parents to become genuine partners in their child's education in whatever role suited them best (i.e., teachers, volunteers, decision makers, etc.) (Wright & Church, 1986).

Some of the lessons learned from literacy education could have a strong impact in technology education. However, although most parents are comfortable helping their children with early literacy, the same is not true with technological fluency. When parents read, sing, and make rhymes with their very young children, they are immersing them in the world of language. What is the equivalent in the world of technology and engineering?

Whenever I ask groups of parents how many of them have read to their very young children or played with written words before they started formal schooling, invariably all of the hands in the audience go up. When I ask the question focusing on how many have done the equivalent in the world of technology and engineering, such as opening up a broken telephone, disassembling a bicycle, and screwing a screw, very few hands go up. And most of those belong to engineers or computer scientists.

Although at first sight reading a rhyming poem and disassembling an old television are very different, developmentally speaking they are not. Both introduce young children to the wonders and mysteries of a particular realm of knowledge. They afford opportunities to encounter powerful ideas, establish personal relationships with them, and ask questions to learn more. However, disassembling a television is more like discussing the meter and structure of a poem, than writing a poem. In the same way that we want children to be able to read and write, we want them to learn how to understand how technology works and to create their own technologies.

Following the basic premises of the Parent Education Fellow, Project Inter-Actions, a research program I created to understand how to help parents develop technological fluency along with their children offers a unique opportunity to investigate how parents can become learners simultaneously with their children, while providing support and guidance (Bers et al., 2004; Beals & Bers, 2006). Based on this work, in Part II, Chapter 4: "Designing the Environment: A Practical Guide," there is a section on how teachers can engage parents in supporting work with robotics in the classroom.

Buying multimedia applications and educational software for the home is not always the best way to engage parents in supporting children's learning. Technological fluency is measured not by how much children learn with computers and how many new skills they develop, but by children's ability and confidence to use technology to create, design, build, and program personally meaningful projects. I often find simple tools as good as some of the most sophisticated multimedia applications. For example, using the paint software and word processors that come with every computer is a good way to introduce children to the idea that they can use computers to make their own projects, such as drawing and playing with colors and lines or writing a story and changing font and type size. Although most educational software teaches new concepts and skills, it cannot teach children how to see themselves as good learners.

With the continuous advances in new technologies and applications, learning how to learn is the only viable recipe for success. Thus, parents have an important role to play—which goes beyond purchasing the latest software for their children. Parents, as in any other domain in early childhood, need to model what learning with and about technology is all about—as they do with language, by talking and engaging in conversations with their children; as they do with literacy, by reading to their children; and as they do with table manners, by using forks and knifes.

However, although most parents feel confident about their ability to sit in a proper way at the table and teach their children by example, not all parents feel the same way with respect to computers. This is not unique to technology, and parents have always struggled to support their children's learning about things they do not know themselves. In illiterate rural communities, parents face the challenge of helping their children learn their ABC's. Immigrant parents face the challenge of helping their children with homework in a second language. Parents of adolescents need to learn the popular vocabulary used by their growing children. However, there is a difference between these examples and the world of technology.

The next generation of parents of young children will be *digital natives* born after 1980 and with constant access to digital media and technology, instead of *digital immigrants* as most of us are (Prensky, 2001). These digital natives would have spent more time watching television, playing console games, and using cell phones than reading books before adulthood. Thus, they will have some familiarity with the world of bits and atoms and will not be afraid of technology. The same will be true of the early childhood teachers of tomorrow.

Today we are still in transition, and many parents (and teachers) are digital immigrants. The challenge for early childhood educators is the need to help parents who are digital immigrants to find ways to learn about technology and engage their own children in activities that will spark their curiosity and help them develop "readiness." As in any other domain of learning in early childhood, parents have an important role as the first teachers of their children. If we help parents to put themselves in the role of learners, at least three benefits can be gained. First, parents can model learning, asking questions and trying many times when things do not work as expected. Second, they can provide helpful assistance for teachers who want to use technology in the classroom but need more adult hands (this is especially true when working with robotics). Third, and most important, parents can begin to reflect about their own learning experiences and perhaps can become strong advocates for the power of learning with technology. These parents can be potential allies for teachers who are seeking systemic educational change and see the computer as an agent of that change.

In this chapter we have gained an understanding of the supports that need to be put in place for developing constructionist learning environments that promote positive technological development. We also learned that when technology is used with constructionist philosophy, socioemotional development coincides with learning powerful ideas from disciplinary realms such as math, science, computer programming, and engineering. In Part I of this book, we have been talking about technology in general, or more specifically about constructionist technologies that enable children to design, create, build, and program. Part II focuses on a particular example: robotics construction kits.

BUT BEFORE WE MOVE ON to Part II, two educators who have used robotics in early childhood discuss their experiences. First, Chris Rogers, professor of Mechanical Engineering and Director of the Center for Educational Engineering Outreach at Tufts University, shares a wealth of knowledge about classroom management while using robotics with young children. Second, Megina Baker, a preservice teacher doing her student teaching in a kindergarten class in the Eliot-Pearson Children's School, shares her experience developing and implementing a curriculum unit focused on the engineering design process. Part I concludes with an interview with an expert in sociocultural theories of child development and education, Dr. Rebecca S. New. The interview focuses on conflicting views and anxieties regarding the developmental appropriateness of children's learning opportunities with robotics.

VIGNETTE

A Well-Kept Secret

Classroom Management with Robotics

Chris Rogers

Chris Rogers is a professor in Mechanical Engineering and Director of the Center for Educational Engineering Outreach at Tufts University. He has been working closely with LEGO Education in bringing LEGO bricks and robotics into the classroom to teach math and science as well as engineering.

Why LEGO Engineering?

Ten years ago, I started working with a teacher at a local school who was simply scared of the technology involved with building and programming a robot. After 3 years of volunteers working in her classroom, she still let the volunteers direct the classroom while she watched. Even now, when she runs the classes on her own, she admits that she feels that she cannot build very effective robots and has trouble answering the children's questions. So why does she continue to do it? Robotics and engineering are hardly required in the first-grade classroom. She says she does it because she sees the excitement and enthusiasm the children have in learning through building, and because the children ask for it. She has students coming in during recess or staying after school to work on their projects. She has the whole class staying on task for over an hour. She sees them eager to learn math and science, and asking insightful and meaningful questions. Finally, she sees students that previously were disengaged (and often troublemakers) becoming engaged and better class citizens. Our Center (the Center for Engineering Education Outreach at Tufts University) works with over a thousand of these teachers around the world through LEGO Robotics and ROBOLAB™ (a product we developed that is sold by LEGO). RoboLab is currently in 15 different languages and over 30,000 classrooms. I have heard this teacher's story from teachers from almost every continent (Antarctica is the only one missing!), with children of every age, race, gender, and socioeconomic background. That is part of the reason I am convinced we have to start introducing more engineering problems into the younger grades. We can do this with a number of tool sets, but I will highlight LEGO Mindstorms because I have had the most success with it in the classroom.

Numerous teachers have shared with me their initial anxiety and concern about bringing LEGO Engineering into the classroom. A Norwegian teacher, for instance, told me how she brought out the boxes (despite her fears) and nothing worked, so she locked them away. A year later, her students convinced her to take them back out, and this time it was successful. She now talks about how impressed she is with what the children are making, how long they stay on task, and how excited they are to learn. Many teachers are motivated to bring engineering into class because of changes in student behavior. An Australian teacher told me about a child who disrupted class continuously until he found his niche in engineering. He soon became a major leader in the class. A friend of mine, who directs a school in Luxembourg, saw one student find direction and companionship through the engineering projects that helped him through a family tragedy. In all of these cases, it is the excitement, creativity, and engagement of the students that have most surprised and impressed the teachers and me. It is the fact that students of all ages are eager to improve their math and science skills that causes these teachers to bring out the LEGO bricks every year.

So is LEGO Engineering the solution to our current crisis in science and engineering education? I do not believe so. I do not think that there is any one solution that will work with all children. Further, I do not believe that any tool can be an effective teacher. The only solution to the crisis, in my mind, is to help teachers implement increasingly complex mathematical and scientific concepts in the classroom. In some cases, this implies changing how we train our teachers. We need to increase teacher self-efficacy in these fields. In other cases, this means getting the tools and curricula into the classroom. In almost all cases, it means reducing class size, changing the way we teach, increasing teacher autonomy, and allowing the teacher to create and innovate.

What Are the Obstacles and How Have Teachers Gotten Around Them?

There are a number of obstacles to bringing LEGO Engineering into the classroom, from cost to training to the current all-consuming emphasis on reading in the elementary school. Even putting these obstacles aside, teachers have a tendency to teach the way they were taught, and systemwide reform is difficult to implement. As with all other subjects, engineering builds from previous years, and so for a program to build, every classroom must be teaching the material. Whereas it is common for one or two "maverick" teachers in the grade to bring this kind of innovation into the classroom, it is much more difficult to have every teacher do it. Overcoming these obstacles requires leadership within the school and the parent community. Both groups need to understand the increasing need for engineering and technology education in our society and commit to a systemwide reform.

To properly bring hands-on learning (or engineering) into the classroom, the classroom must change from a teacher lecturing to a teacher being a mentor. Instead of the teacher driving the questions, now the students must drive the questions. Instead of everyone sitting quietly in their seats, the students are moving around, interacting, and talking. In general, where order used to reign, teachers are now teaching "through chaos." These changes are often easy to discuss but difficult to enact. It is tiring for any teacher to deal with so much activity for long periods. I have seen a number of different innovative solutions in classrooms I have visited. Some teachers reduce the chaos by giving different team members specific roles (such as programmer, builder, historian, etc.). In this way, she can pull aside a subgroup (for instance, all programmers) and discuss specific issues with the smaller group. She can send a subgroup to the library to do research, or simply have some of the programmers help each other. The students quickly identify fellow-experts and often can get all the help they need from peers. Other teachers limit options—by reducing the number of available building pieces or computers. This forces the students to collaborate more and think before building. Most of the teachers find class discussions (or circle time) at the end of the session to be invaluable in ensuring that the students are learning the material. Often it is here that the children transfer their newly learned knowledge to their environment.

How the teacher sets up her classroom can make a large difference as well. Two of the most common problems are classroom cleanup

(LEGO pieces have the ability to get everywhere) and pulling apart models. LEGO delivers sets with bins to contain all parts, and some teachers have the students continually sort the sets in an effort to keep all the pieces together. This is often difficult to do, as some of the smaller pieces get lost or end up in other people's models. Other teachers will combine all of the little parts into bins in the center of the classroom, and this way teams are only responsible for the more expensive parts (the RCX, motors, sensors, etc.). This makes cleanup faster, as there is one bin for all axles, one of all gears, and so on. The LEGO plastic bins work well as containers for the group models and can easily be stacked in the corner when not used. The second issue is how to share sets across classes. This is only an issue for schools that have a technology teacher separate from the classroom teacher. The problem is that the 10:00 class has packed away their models but the teacher needs the sets again for the 11:00 class. Because the 10:00 class will not take kindly to having their models torn apart, the teacher has a problem. Some teachers restrict the class to very simple builds, have prebuilt models, or simply do not have the 11:00 class do LEGO Engineering until the 10:00 class has completed the unit. A few schools have been able to afford enough hardware for multiple classes.

Teachers often wonder if they should have their students build from instructions or have them "free-build." Being an engineer, I always prefer the free-builds because the students appreciate the chance to be creative and produce a project different from their neighbor's. It does, however, come at a cost. Students are more likely to have problems, they will require more individual attention, the class will move forward more slowly, and the group discussions will not be as focused, because different groups will have different issues. It is these differences that can often lead to the best learning environment, as long as the teacher identifies and builds on the differences. In general, I have found that new teachers (and students) prefer to have some sort of starting instructions. Some teachers will begin the class out with an "instruction build," but then let the more advanced students modify and personalize their construction while waiting for the other students to complete their work. Once the students have more experience with designing and programming, the teacher opens up the free-building activity in the final project with a discussion of an "engineering design brief" and some of the attributes of the engineering design process (such as problem definition, brainstorming, designing, testing, and redesigning). Many teachers have the students keep engineering logs to document and assess/grade this process.

Affording the materials is challenging. Any hands-on tool set is expensive, and the LEGO bricks are no exception. The main advantage they have is that they are completely reusable, so the recurring costs are a lot less than using clay, straws, and so forth. In fact the only recurring cost is replacing lost parts, which is usually done quite cheaply. The start-up cost, however, is substantial and most teachers write grants or appeal to the community to raise the money. The most successful program I have seen in this regard was an elementary school in New Jersey that ran a “parent engineering night” that was so successful that the PTA and parent community financed materials for the fourth grade. The program at the elementary school now spans all the grades.

Finally, the last major obstacle I have seen for teachers is that there is no one right answer in the world of engineering. In reading, math, and most science in the elementary school, the answers are all known and the teacher can tell the student if he or she is on the right track or not. In engineering, there is no “right track,” just some solutions that work better than others. This means that the teacher can no longer be the source of all answers, and often the teacher’s response is “I do not know.” Some teachers take a while to become comfortable with this approach.

But What About the Girls?

Often in the first-grade classroom, the girls have never really played with LEGO bricks but happily tell me how their brothers play with the bricks. Why is that? LEGO has spent years of market research trying to find a product that will appeal to girls. In my experience, girls approach an engineering project in substantially different ways from boys. The male is happy to just build, whereas the female often wants a reason—such as building a hospital, a city, or a ski resort. The girls often like the building time because they get to build with their friends. In fact, one first-grader we interviewed said this was the reason why she looked forward to engineering time at school yet never played with the bricks at home on her own. The boys, on the other hand, often have to be taught how to build together and would prefer being alone. My favorite difference, however, is in the approach to building. If the teacher presents a problem to a classroom and then places the LEGO bricks on the table, almost all the boys grab pieces long before they have any idea of what they are going to build. Many of the girls, however, think (and discuss with their friends) what they are going to build before choosing pieces. This causes problems with "rare" pieces disappearing early and with boy/girl groups. By the time she has figured out what she thinks they should build, he has already started to build and will not rip apart and start again. The girl gets frustrated and becomes disengaged. Teachers will often have single-sex groups or will require a drawing or a brainstorming session before bringing out the LEGO bricks to avoid these issues. The interesting thing is that I have seen this in adults as well—we do not seem to grow out of these mind-sets. I definitely grab first and think later, despite years of engineering training.

Is It All Worth It?

We are asking teachers to change the way they teach (from lecturer to mentor), we are asking them to intentionally increase the chaos in the classroom, we are asking them to teach differently from how they were taught (and how they learned), and we are asking them to learn a new subject, engineering. Finally, our tool set is not cheap, the curricular activities are relatively new, and few of their friends and colleagues have gone down this path. So the question "Is it worth it?" is very valid. The answer depends largely on the teacher, the school administrator, and the local parents. From a learning perspective, there is no doubt in my mind that the hands-on nature of engineering increases the children's enthusiasm to learn and motivates them to understand the math and science behind their constructions. There is also no doubt that the familiarity with LEGO bricks and the excitement of robotics and automation increases their enthusiasm for "LEGO time." It is teacher guidance, however, that teaches the student how to learn on her own and how to transfer this knowledge from the LEGO world to the real world. About 80% of the teachers with whom we work have decided that the added effort was worthwhile and have continued to bring LEGO Engineering into the classroom. Some teachers have completely changed how they teach, integrating engineering throughout their curriculum, whereas others have developed a number of "LEGO units" that they pull out throughout the year. Still others have replaced the LEGO world with saws, screwdrivers, and drills. In all cases, the students' excitement and pride in their accomplishments always convinces me that it is worth it.

What Next?

As more and more teachers bring engineering into the classroom, we need to build a support network and a community. I think Wikipedia is one of the best demonstrations of the power of a community that cares. Can we develop something similar for LEGO Engineering? Something where the proficient teachers can easily share their knowledge and experience? A place where new teachers can find new avenues for innovation? My dream is that someday teachers will be pushing LEGO for more innovation in their tool set, because they will have exhausted what is currently available and that school administrators will be pushing their local engineering colleges to collaborate to help increase student excitement in learning through engineering. Imagine a world where learning to build is as important as learning to read.

VIGNETTE

The Engineering Design Process in a Kindergarten Study Group

Megina Baker

Megina Baker is a graduate student in the Master of Arts in Teaching program at the Eliot-Pearson Department of Child Development at Tufts University. She works half-time as a Graduate Teaching Assistant in the kindergarten class at the Eliot-Pearson Children's School and greatly enjoyed her first experience implementing a technology curriculum.

As a new assistant teacher in the kindergarten class this year, I was excited to try out a new curriculum structure that the head teacher, Ben Mardell, uses in the classroom. Rather than selecting a theme for the entire class to focus on, Ben chooses to work in study groups. These are groups of three or four children working with a teacher to explore a topic of interest. It was October, and while planning our first round of study groups of the year, Luis gave us a wonderful idea that led to a rich learning experience for both the children and me.

Luis was the only boy new to the kindergarten class this fall. He was learning English as a second language and needed an entry point to connect with other members of the group. His mother mentioned to the teaching team that Luis "wants to become an engineer when he grows up," and this sparked the formation of the Engineering Study Group in the class. Naturally, Luis was in this group, along with three other children: Aidan, Iman, and Brian. These children had each expressed some interests in building with LEGO bricks, but we had not observed them talking about engineering before. Because I did not have previous experience working with motorized LEGO parts or the RoboLab software (used for programming our LEGO creations), I contacted the Tufts College of Engineering and was connected with two students in the Student Teacher Outreach Mentorship Program (STOMP): Mark and Dania.

These undergraduate students would be available to join our group on Friday mornings throughout the project, providing us with the LEGO materials we needed for building and programming motorized constructions and providing building and programming support. Mark worked with our group, while Dania supported a second study group.

Project Goals

My initial goals for the Engineering Study Group were that the children would have exposure to the concept of LEGO Engineering, would interact with "real" engineers who could act as positive role models, and would explore the powerful idea of the engineering design process. I hoped that the children would be able to extend their knowledge of the design process to other projects and domains, perhaps by referring to the revision process of design when troubleshooting a block structure that refuses to balance.

In addition, the project would address at least one of the National Science Education Standards for children in grades K–4 (http://www.nap.edu/readingroom/books/nses/html/6c.html):

- Abilities of technological design
- Understanding about science and technology
- Abilities to distinguish between natural objects and objects made by humans

The Initial Provocation

A firm believer in the idea of emergent curriculum, I wanted to first observe the children in my group and become aware of their interests before planning the curriculum further. Our first session, known as an "initial provocation" in the language of study groups, was an open-ended play session. During this session, a preconstructed LEGO structure was presented to the Engineering Study Group, and the children were invited to play with it using LEGO figurines, making suggestions about changes or additions that they might like to see in the structure. I was curious to see if the children would mention concepts of motion (e.g., a door that could open), which could lend itself to the next steps in our project. If the children did not explore this route, I would be

FIGURE 7. Playing while building

prepared to pose questions to them during their play that might encourage thinking about movement.

As the children played with the structure, several exciting ideas emerged. Brian and Iman began to play with the structure first, and Iman (observing the sea creatures present in the structure) announced, "It's an aquarium." As often happens in children's play, the group immediately accepted this idea, and they proceeded to use the LEGO figurines to play with the structure (see Figure 7).

This idea was followed by another: looking at two levers at the top of the rectangular wall, Brian made a suggestion that would power the rest of our engineering explorations. "Hey look!" he called to the others, "They swim when you push the levers!" As Brian used his LEGO man to move the levers, Aidan, Luis, and Iman joined him in making the sea creatures in the aquarium swim. Iman's idea of the aquarium, so readily accepted by the other children, coupled with Brian's idea to have the sea creatures move by pushing levers, had provided us with the momentum we needed to move our group toward success. With the children clearly on board, we ended the session on a high, and I set to work planning our next steps with the help of the engineering students and the kindergarten teaching team.

Curriculum Planning

Following the success of our initial provocation, I felt ready to generate a more detailed plan for the group. Because I believe it is important to maintain flexibility when designing meaningful curriculum for young children, I began with a basic plan for the flow of the project but was unsure at the outset how many sessions we would need to complete the design process (in the end, our project lasted about a month, during which we met twice weekly for 30–50 minutes at a time). Based on the children's interests in aquariums and aquatic animals, I decided to invite them to create aquatic animals of their choice from LEGO parts.

As the project progressed from planning our creatures to building and troubleshooting, I kept a documentation binder that included descriptions of our work and quotes from the children, as well as photographs and drawings of our project. This documentation was available for parents, and some portions were e-mailed out to families to keep them connected with what their children were doing at school. This documentation was also used in writing progress reports on the children at the end of the semester.

Implementing the Curriculum

Our work began by gathering background information on LEGO materials and on aquatic creatures that would later inform the design process. We spent our first session creating an aquarium habitat in the classroom, and another taking a field trip to the New England Aquarium (Session 2), where we photographed and sketched aquatic animals of interest (the children were most curious about turtles and crabs), paying attention to the ways in which they moved. Then the engineer-

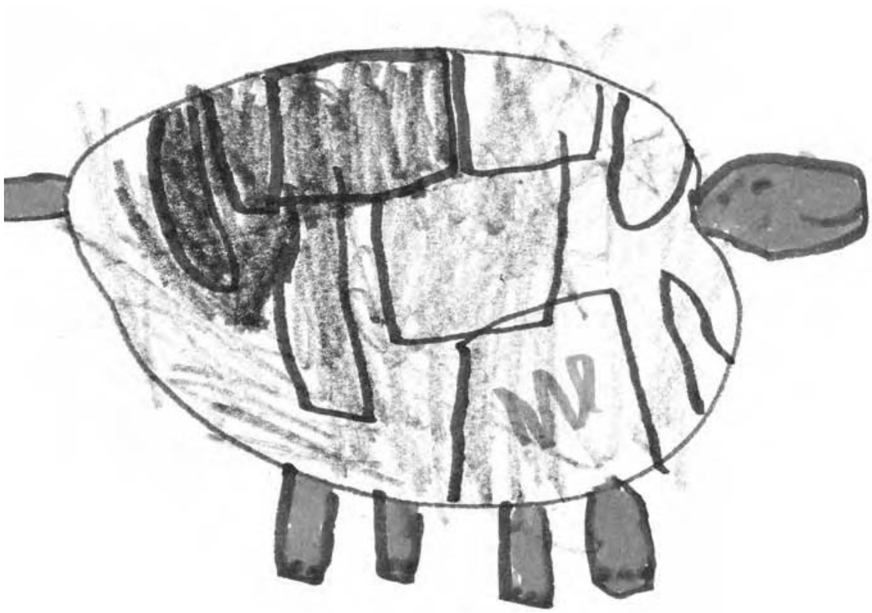


FIGURE 8. Drawing before building: design journal

ing students brought in some LEGO creations (Session 3), some with motors and some without, as a provocation to pique the children's interest in motors and to open a dialogue about what motors do.

Having gained some initial information about our topic, I invited the children to start sketching their creations. I encouraged them to work together and, fortunately, this idea was received well. By the end of our fourth session together, Luis and Iman had sketched a crab and outlined its moving parts, while Aidan and Brian had engaged in a fascinating conversation about turtles' ears, ending up with a concrete sketch of a turtle, "with a little pointing mouth and four feet that swim" (see Figure 8). We were ready to begin building!

For the next five sessions, Mark, the engineering student, supported the children as they constructed a crab and a turtle using the LEGO Mindstorms technology. Mark assisted the children with the more challenging aspects of creating their creatures, such as connecting the motors to their power sources. Of course, claws fell off, and the motor cables got tangled in the turtle's feet. These were natural opportunities to reinforce the ideas of the design process, chances to encourage the children's thinking about specific problems and brainstorm new solutions (see Figure 9).

FIGURE 9. Building together

When the creatures were ready to be programmed, Mark incorporated the children's ideas about how their creatures should move ("we want the turtle to go backwards and forwards") and created simple programs to attain their goals. In a following session, we invited the children to manipulate their creatures again, this time altering the programs and the motor connections to see what they could change about the motion. We laughed together as we succeeded in making the crab's claws spin faster and faster and got the turtle to "swim" backward, and the children beamed as they shared their finished creations with the whole class.

A few weeks after our study group had come to an end, I gathered Luis, Iman, Aidan, and Brian once more to look through our study group documentation binder together. As we turned the pages, reminiscing about our challenges and successes together, the children became inspired all over again. Brian cried, "Let's do it again!" and Luis's wide grin indicated his full approval of this idea. The LEGO Mindstorms kits were brought out again, and the two boys spent the rest of that morning configuring motors and gears, competently manipulating a technology that had once eluded all of us. Best of all, when Luis asked for help connecting one of his motors, I no longer hesitated about what to do. Mark's support had made a difference to us all.

Extending Engineering

Fortunately, the kindergarten's experience with engineering and LEGO Mindstorms didn't end with the conclusion of our study group. Rather, engineering became a part of our classroom culture. Mark and Dania continued to visit our class on Friday mornings, inviting any interested children to pursue further explorations with engineering. Luis was a regular participant, spending weeks working on cars while deepening his understanding of wiring connections, circular motion with motors, and wheels. In a recent session, he created a car that spun in a circle and then reversed. The Engineering Study Group had enabled Luis to find his place in the class through a curriculum entry point that met his individual interests and skills. The whole class had come to view Luis as an "engineering expert," and we had all become engaged in the power of engineering and design.

By maintaining our relationships with the engineers, the children continued to explore the LEGO Mindstorms technology more deeply throughout their time in kindergarten. This experience left the children feeling empowered about their abilities to plan, design, and construct projects of their choosing. It certainly empowered my teaching. Given the right supports and an adventurous mind, exploring an unfamiliar technology became a uniquely rewarding challenge.

INTERVIEW *with* REBECCA S. NEW

Moving from "I Know" to "I Wonder"

Revisiting Developmentally Appropriate Practices in the Light of Sociocultural Theories

Dr. Rebecca S. New is an associate professor of child development at the Eliot-Pearson Department of Child Development, Tufts University. Prior to this appointment, she was professor of education at the University of New Hampshire. Dr. New's scholarly work in the field of early childhood education has centered on the challenges of curriculum for the 21st century, culturally diverse interpretations of the constructs of quality and developmentally appropriate practices, and the necessity of expanded interpretations of teachers as researchers and parents as active participants in children's educational experiences. These foci are represented in her research on the cultural bases of children's early learning and development, including a recent collaborative study on home–school relationships in Reggio Emilia, Milan, Trento, Parma, and San Miniato, Italy.

MB (Marina Bers): *You are an expert on sociocultural theories and education. How do you think sociocultural theories can inform work with technology and young children?*

RSN (Rebecca S. New): Well, that's a wonderful question and I'll try to give a useful answer, even as I acknowledge that the question itself provokes some new thinking on my part. I believe that sociocultural theory could help us in at least three ways in our thinking and planning about children's explorations with technology. I'll begin by talking in a more general way about how sociocultural theory has helped us to understand the situated nature of children's development, the variety of interpretations of developmentally appropriate practices, and the processes of learning and development.

First of all, it is worth remembering the sources of sociocultural theory itself. Many people credit Vygotsky (1978) for helping us recognize and understand the cultural bases of human learning and development. Vygotsky's theoretical interpretations have been supported and elaborated upon by anthropologists and cultural psychologists. John and Beatrice Whiting's *Children of Six Cultures* (Whiting & Whiting, 1975) study vividly demonstrated the embeddedness of children's learning and development in *particular* places. The construct of the "developmental niche" (Super & Harkness, 1986) has since been used to illustrate this interface between children's development and the visible and invisible characteristics of their sociocultural environment. Cross-cultural research clearly demonstrates that children's developmental trajectory will vary as a function of the resources and opportunities available to them, the company that they keep (Whiting & Edwards, 1988), and the values and beliefs of those responsible for the children's early experiences. So, for example, children in middle-class American families are generally encouraged to develop and use their verbal skills at an early age, whereas children in other settings are taught to observe and respond to adult language upon request. Thus, a very talkative child in a middle-class White American family is generally regarded as competent and advantaged, whereas that same child in another cultural group might be viewed as rude, undisciplined, and poorly raised. Let me underscore this point: sociocultural theory reminds us that there are culturally distinct views of optimal child development.

A second and obviously related contribution of sociocultural theory to early childhood education is to reveal multiple interpretations of what might be considered "developmentally appropriate" educational practices. For example, our observations of classrooms in Reggio Emilia have helped us to recognize that direct instruction from teachers is not always at the expense of children's interests and capacities to engage. Indeed, those observations resulted in major changes in U.S. interpretations of developmentally appropriate practices, as evidenced by changing guidelines (Bredekamp, 1987; Bredekamp & Copple, 1997). Other differences are perhaps more provocative, such as those revealed in studies of cultural groups where it is sometimes deemed both necessary and desirable to teach children to care for one another. Japanese preschools (Tobin, Wu, & Davidson, 1989) and primary grade classrooms (Lewis, 1995) include large group sizes with explicit expectations from teachers that children will assist and evaluate each other.

In many American classrooms, in contrast, we urge and eventually expect children to mind their own business and take care of themselves. We call these competencies "self-help skills," and they are a part of most U.S. readiness assessments. I had never considered such a goal to be problematic until an Italian teacher asked why I would want to "teach children that they don't need anyone else's help." I continue to ask myself that question, even as I recognize its relationship to mainstream American values of autonomy and independence. At the least, these different views of effective and desirable teaching practices—and sociocultural theory in general—remind us that concepts of competence vary from setting to setting, as do interpretations of developmentally appropriate educational practices (Mallory & New, 1994).

A third contribution of sociocultural theory to early education—and the one that is likely the best recognized—is its illumination of pancultural and particular processes of learning. As interpreted by scholars such as Barbara Rogoff (2003) and Jerome Bruner (1990), we now have a much deeper understanding of the wide range of learning potentials that can be tapped as children apprentice to their various communities of practice. We understand now in ways previously unrecognized the inextricable relationship between cognitive development and social relationships, including the contributions of sociocultural conflict to cognitive engagement (Forman, Minick, & Stone, 1993). The theoretical construct of guided participation sheds new light on the myriad of possibilities for teachers to promote children's early learning. The notion that children utilize their experiences with one another and with adults to explore and build on ideas that are within their "zones of proximal development" has helped teachers to recognize anew *and legitimize* the potentials of children's play, of mixed-age groupings, and of long-term and open-ended projects. This work also helps us to imagine new and as yet unrealized potentials of adult–child relations and collaborative inquiry as essential components to an early childhood curriculum.

MB: *And how is this related to technology?*

RSN: Well, technology as an artifact of the 21st century is a perfect illustration of many of the premises of sociocultural theory that I have just described. Certainly in terms of adult development, there is the general expectation that if we are to be employable, it is essential that we are technologically literate. The easiest analogy is with respect to literacy. No one questions whether or not literacy is an imperative for successful adult functioning, and few find fault with literacy's primary place in educational priorities, even for very young children. Although some—myself included—are concerned that a too-early emphasis on literacy may preclude young children's exploration of other parts of the human and natural world, most agree that all young children can benefit, with pleasure, from the opportunity to explore the world of print, especially when introduced by adults and older peers with pleasure and enthusiasm. Technology is, in my view, yet another communicative tool much like the pencil, the felt-tipped pen, the paintbrush, or the telephone. It is a part of most children's lives, and to preclude their opportunity to touch, to talk about, and to explore technological tools makes no more sense than to keep children out of libraries or away from cell phones. That is *not* to say that they would benefit from an unguided exploration of such spaces or objects. Rather, the point is that children have the desire, the need, and some would say the right to observe and engage with the essential features of the world they are living in.

MB: *But many early childhood educators are also concerned because they claim that sophisticated technologies, such as the one this book discusses, might not be developmentally appropriate.*

RSN: Here is where my views of developmental appropriateness are informed by my understandings of the relationship between learning and development. Rogoff's (1990) examination of Piagetian and Vygotskian interpretations has been helpful in capturing critical differences in their theoretical interpretations of cognitive development. If we assume, as Piaget did, that development precedes and determines what can be learned, then we would be wise to keep children from exploring things that they don't yet understand. But this would suggest that the very young children should be kept out of churches or synagogues, since surely those scripted religious experiences are "over the child's head." But if we consider Vygotsky's notions of learning as a means of stretching or pushing along developmental processes, then we can recognize what we have intuited all along, which is that the child is capable of gradually appropriating what it means to be Episcopalian, or Jewish, or Muslim. This same child can, with guidance, learn to make sense of and utilize a remarkable array of contemporary tools—including cell phones as well as robotics. And to the extent that this tool use contributes to their developing capacity to engage in culturally relevant social activities and community practices, then such tool use is, by my definition, developmentally appropriate.

A second reason for allowing children to have access to and learn about technologies such as robotics comes not from child development theory but from a perspective of social justice. Technology is a lot more than a tool. It is a form of cultural knowledge that has the symbolic power of a marker of affiliation (Kantor, Elgas, & Fernie, 1993)—something that distinguishes groups of people from one another with the result that some groups are marginalized. Technological expertise is now a form of social capital that is associated with many features of economic and educational success; and schools have a responsibility, in my view, to create an equal playing ground so that no child is precluded from learning about and eventually developing such competencies (New, 1999b).

MB: *Some teachers working with robotics are afraid of losing control. The interview in the next part of this book with Terry Green, an experienced teacher, talks about chaos in the classroom.*

RSN: Teachers are trained—and I use that word with reluctance—to maintain control over their classrooms. They are also expected to have control over their curricula. And yet most would agree that control has its limits *and is limiting* when our goals include the promotion of exploration, innovation, and critical thinking. It is true that technology is not so easy to control, due in part to teachers' lack of experience in that domain but also because technology is open-ended. The child with a box of LEGO does not need to follow directions in order to construct something, any more than the child with robotics materials has to work in a particular sequence in order to learn, just as putting anatomically correct and ethnically diverse dolls in the dramatic-play corner may be of some risk. But surely some risks are worth taking, especially as they open up opportunities for both adult and child learning (New, Mardell, & Robinson, 2005).

And this leads me to my final comment about the notion of developmentally appropriate practice. When we talk about zones of proximal development, we are almost always talking about children, but adults are also in various states of readiness to learn new things. If we could imagine that, on occasion, children could be our "more competent other," then we could begin to envision schools as places where *everyone* has something new to learn. Certainly, increased technological fluency promises new interpretations of Vygotskian conjectures on the relationship between thought and language (Vygotsky, 1962). Unfortunately, such an interpretation of collaborative inquiry very rarely characterizes classrooms . . . unfortunately. We talk about collaboration among children and maybe among teachers, but not often among teachers and children, and even less do we bring parents into such collaborative learning communities. Technology has the potential to open up such pathways of discovery for multiple stakeholders.

MB: *How do you reconcile this vision of teaching and learning as collaborative inquiry with increasing demands on accountability and testing by the federal government?*

RSN: While it might be difficult to imagine, I seriously believe that technology could help teachers to accomplish more of their educational goals. While it will not make standardized testing any more responsive to the variety of ways in which children learn and demonstrate their learning, it certainly has the potential to help teachers integrate curriculum content. I can't think of anything that couldn't be taught in an enhanced way through technology. I've often thought that we effectively address most curriculum standards through two basic content areas—science and social studies. Technology, and its partner engineering, bridges those two broad bodies of knowledge. Technology in the form of Web sites can help identify the zoos that are in your state. A field trip and subsequent Web- and text-based explorations of zoos could support the study of ecosystems and animal types and feeding strategies.

MB: *And using robotics you can build your own zoo and explore the different motions and movements done by the animals and how they are related to their settings. . . .*

RSN: Yes! Yes! This example makes clear that you are teaching a lot more than robotics. How big a cage does this robotic animal need to be healthy and safe? Even very young children can be supported to examine and consider the consequences of "zoo life" on animal reproductive and mental health. How exciting such a project could be—not just for the children, but the teacher. And what a contrast this interpretation of an early childhood curriculum is to what is now standard in so many classrooms. I am convinced that if the curriculum is limited to what teachers already know how to teach, then regardless of whether or not it is of interest to children, for sure the teacher is likely to be bored and not intellectually engaged. I am confident that the very features of robotics or other forms of technology that make teachers nervous could be exactly what excites them as well, if only they allowed themselves to say, "I wonder" instead of "I know." And perhaps teachers would have the courage to be more curious if they knew that they didn't have to always be the solitary expert in the classroom. Technology has the capacity to integrate more than curriculum content; it also has the potential to integrate people, in the way that your research has illuminated (Bers et al., 2004). Current work that is taking places in countries such as Costa Rica illustrates technology's potential to inform not only child and teacher development, but also community development and social change. That's precisely what John Dewey was talking about almost 100 years ago, and he could have not imagined the tools that we have today to accomplish his vision of a transformative and integrated curriculum (New, 1999a). Yes, technology will generate conflict; but even that has been found to play a powerful and positive role in social development and cultural change (Turiel, 1999). It would be more than a missed opportunity were we not to take full advantage of what technology has to offer us. It would be a crying shame.

PART II

Using Robotic Manipulatives in the Early Childhood Classroom

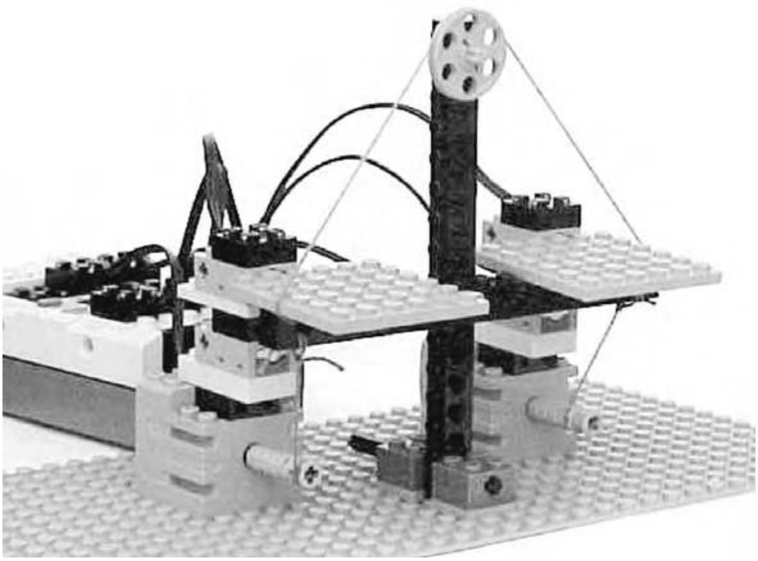


FIGURE 10. A robotic scale to compare weights

Building on the basis of the constructionist theory of learning, covered in Part I, the focus of Part II is on describing robotic manipulatives, giving examples of currently available robotics construction kits, and providing lists of curricular and technical resources for taking this technology into the classroom. This Part also provides examples of powerful ideas we can help children explore by using robotics. Two vignettes are presented, in which early childhood teachers write about their experience with robotics in the classroom by sharing a project. Rebecca Merino and Kevin Staszowski tell the story of how their combined first- and second-grade class designed and built an interactive Freedom Trail after a visit to Boston. Merredith Portsmore describes different experiences of first-graders building a chair for Mr. Bear and other projects in the Engineering by Design curriculum. Part II ends with an interview with an experienced teacher in a suburban school in Massachusetts, Terry Green, who has worked with robotics in early childhood education for the last 10 years. Three appendixes, a list of references, and an index are also provided.

CHAPTER 3

Robotic Manipulatives as Learning Tools

My interest is in the process of invention of "objects-to-think-with," objects in which there is an intersection of cultural presence, embedded knowledge, and the possibility for personal identification.

—Seymour Papert (*Mindstorms,* 1980, p. 11)

I define a robotic manipulative as any construction kit for children involving two elements: construction in the physical world and programming that construction in the computer so it can become interactive and respond to stimulus in the world. After a brief history of early childhood manipulatives, I describe current robotics construction kits available for young children and how they can support learning. Then, I focus on robotics as a medium for engaging young children in developing technological fluency and learning about math and science through integrated curricula in a fun and playful environment.

What Is a Robotic Manipulative?

The word robot comes from the Slavic word *robota,* which means labor or work, and was first used by Czech writer Karel Čapek in his science fiction play *R.U.R.* (*Rossum's Universal Robots*), which premiered in 1921 in Prague. Later on, Russian-born American science fiction writer Isaac Asimov popularized the word robot in his well-known science fiction books. He first used the term *robotics* in 1941 in his short story "Runaround."

The word robot is used to refer to a wide range of machines. They take on different forms, from industrial to humanoid, and they can perform autonomous or preprogrammed tasks. Some robots perform tasks that are too dangerous or difficult for humans, such as radioactive waste clean-up and surgical procedures. Others can automate mindless but very precise repetitive tasks, such as those involved in automobile production. But all robots are capable of movement under some form of control and can be used to perform physical tasks. Thus, these two characteristics, programming and building, atoms and bits, should be present in robotics kits designed for educational purposes, regardless of the age of the children they are marketed for. Children of all ages should be able to program their robots to perform some action in the physical world.

Although in previous decades robots have captured the imagination of children through popular movies such as *Star Wars,* nowadays robots can be found in the house to help with simple tasks such as vacuum cleaning and grass cutting and to provide companionship, such as Aibo, Sony's robot pet dog. Research on social robots that can interact with each other and with humans is a booming field.

With the growing popularity of robotics, the use of robotics kits is becoming more widespread in education, particularly in high schools, middle schools, and elementary schools (Rogers & Portsmore, 2001). Using robotics requires a working knowledge of electronics, mechanics, and software programming. Thus, robotics provides a rich platform for integrating different areas of study through a compelling and engaging hands-on activity. Although early childhood education is slowly starting to develop an interest in the use of robotics for education (Bers, 2007b), most of the work has been previously limited by the complexity of the robotics kits available and the lack of a guiding philosophy for using robotics in a developmentally appropriate way. This books tackles both of these problems by presenting robotics kits that can be used with young children via constructionism.

The use of robotics in early childhood extends a long-standing tradition of learning manipulatives. Since Fröebel established the first kindergarten in 1837, and developed a set of toys (which became known as "Fröebel's gifts") with the explicit goal of teaching concepts such as number, size, shape, and color, educators like Maria Montessori have created a wide range of manipulative materials that engage children in learning through playful explorations (Brosterman, 1997).

Over time, as the gifts and manipulatives were marketed, new tools were developed that more closely resemble what is considered a construction kit today. Building bricks gave way to interlocking pieces, and the self-locking building brick was produced by LEGO in 1949. The metamorphosis of the building brick, from a strictly architectural and engineering toy to one with "technological" properties such as moving parts, starts with timber slats with linking pins, nut-and-bolt connections, wheels and pulleys and other mechanical components that were part of a variety of marketed construction kits, such as Meccano®. LEGO took on these properties as the company developed sets with mechanical parts, namely the TECHNIC I and "Early Simple Machines," which incorporated gears, shafts, and pulleys with the original plastic molded coupling brick (Parkinson, 1999). The characteristics of the pieces lend themselves to children's concrete explorations about mathematical concepts of balance, symmetry, and spatial relations. Nowadays, the use of manipulatives as a teaching tool is widespread, and most early childhood settings also have DigiBlocks, pattern blocks, Cuisenaire rods, and so forth.

In the late 1960s, Seymour Papert began experimenting with adding computation to moving machines called "floor turtles," so children could have control over the mechanical movement. In the tradition of the early manipulatives, the first robotic manipulative was born. Connected by cables to a mainframe, this ground-breaking educational robot could be programmed by children to perform various movements, such as drawing geometric designs with its mounted pen. Since then, "digital manipulatives" have continued to evolve and offer students opportunities to explore dynamic concepts such as feedback, which go beyond what traditional early childhood manipulatives could provide (Resnick, Ocko, & Papert, 1998).

Fueled by Papert's pioneering ideas, in the 1980s the MIT Media Laboratory collaborated with the LEGO Group to create a programmable construction kit. The first product of this collaboration, the LEGO tc logo (as it was named), provided an interface box for children to use Logo to program the movements of their LEGO creation. In 1987, the first prototypes of programmable bricks were used in educational research. However, they underwent many revisions before becoming "sufficiently reliable that they could truly become part of a classroom environment, honestly owned by the teachers and children who were using them" (Martin, Mikhak, Resnick, Silverman, & Berg, 2000, p. 13).

As the variations became available to schools, LEGO developed the RCX brick (Robotic Command Explorer), which became part of the LEGO Mindstorms product line, bringing robotics into the homes of children in the late 1990s (see Figure 11). Using Logo as the programming language, the software evolved into a graphical icon-based program, called "Logo Blocks" by MIT researchers and "RCX Code" for

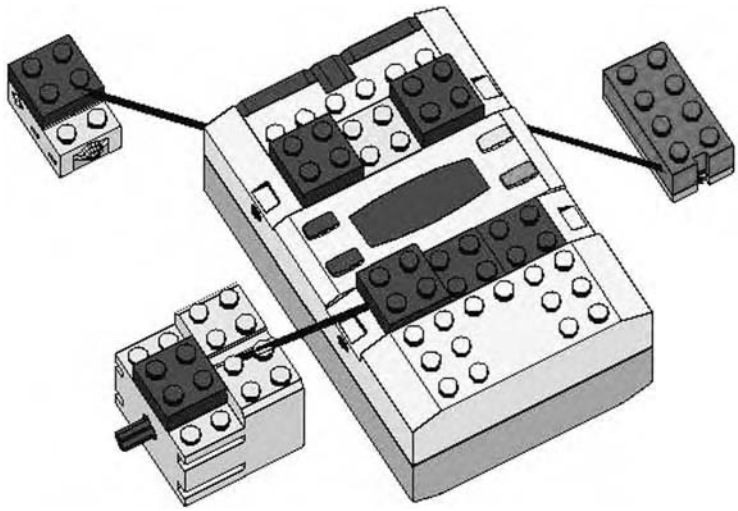


FIGURE 11. RCX brick with a motor, a touch, and a light sensor

retail LEGO kits. At the same time, Tufts University, collaborating with National Instruments and LEGO Education, developed a similar program called RoboLab, which is distributed for educational use with the Mindstorms kit and is currently used worldwide. RoboLab is built on the powerful graphical programming language LabVIEW™, developed by National Instruments. RoboLab is different from the RCX Code in that it was designed specifically for the school classroom—a place with few computers, little support, and 45-minute class periods.

In this book, most of the work described with robotics in early childhood uses the Mindstorms kit and RoboLab. The kit contains a large LEGO brick with an embedded microcomputer, called the RCX brick, an infrared USB tower that connects the RCX to the computer, and a variety of LEGO pieces in different sizes and shapes. The programs children create in the computer can be downloaded to the RCX brick. Children can use other LEGO bricks or diverse materials to build their own robots around the RCX brick, which takes the place of the "robotic brain." Once the program is downloaded into the RCX, robots can be autonomous. Some of the pieces included in the kit are familiar, such as beams, bricks, and plates. Others are unique to robotics, such as motors, light sensors, touch sensors, wires, axles, and gears. The RCX has three input connections (for the touch and light sensors) and three output connections (for motors and lights). In addition, an LCD display provides information about the motors and sensors, as well as data stored in the processor. An infrared connection allows the RCX brick to communicate both with the tower and with other RCX bricks (see Figure 12).

When introducing the RCX brick to young children and adults alike, I like to use a simplified anthropomorphic metaphor. The RCX is the brain, the motors are the legs, the touch sensors are the hands, and the light sensors are the eyes. In that way, children understand that the RCX receives information about the outside world, as the brain does, through the sensors, and can move through the motors. The kind of movement it does depends on what the brain, the RCX, tells the motors. And that is decided in the programming environment (the set of instructions the RCX brain follows). Sometimes I even have one of the children pretend to be a robot and I ask the rest of the class to program him or her to perform a simple task, such as walking toward a wall without running into anything.

Children can include the RCX brick in the building of their project. Because it does not need to be connected to the computer (the program can be downloaded through the tower), children have flexibility in the type of creations they can make, as well as in deciding the behaviors of their projects. They can create a moving car that follows the light or a merry-go-round that plays their favorite tunes. To program behaviors for their robotic creations, such as motion and reactions to stimuli (e.g., if there is light, then go forward; if the touch

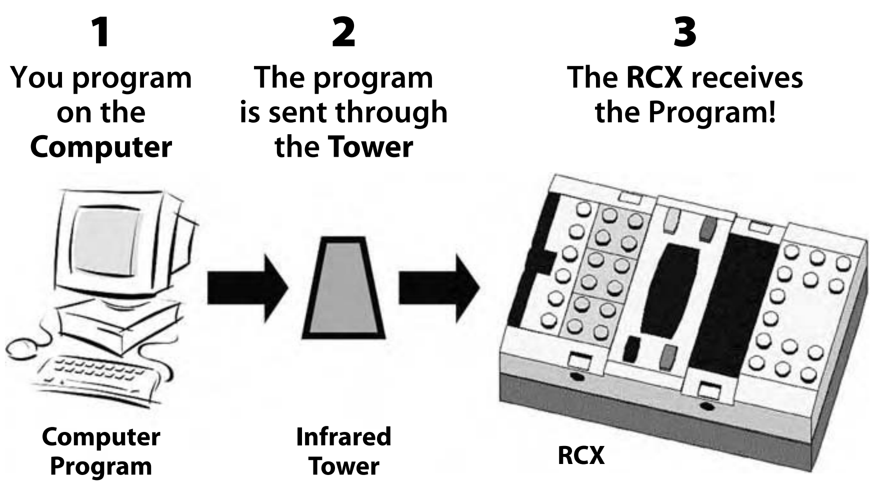


FIGURE 12. The three different elements involved in working with LEGO robotics kits

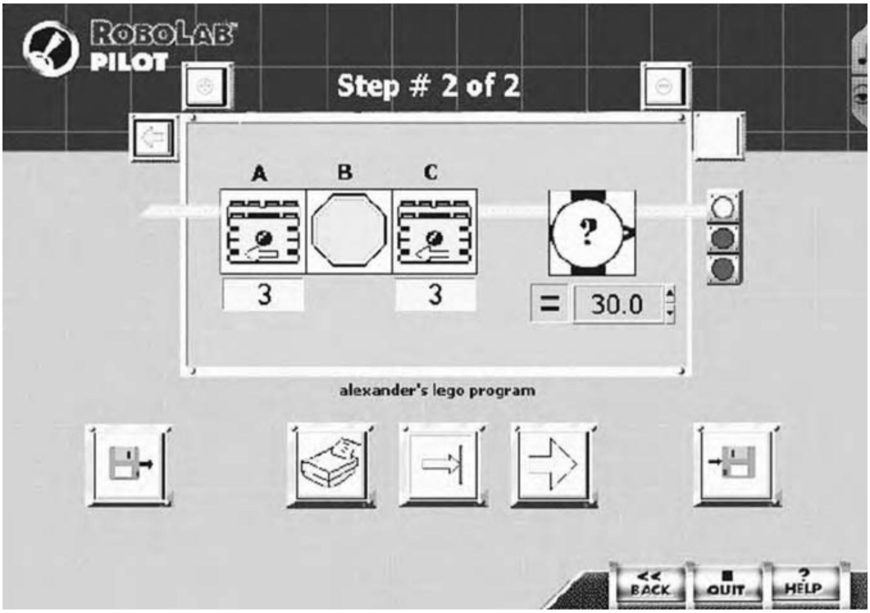


FIGURE 13. RoboLab Pilot level

sensor is pressed, then play a sound), children can use RoboLab or the Mindstorms software that comes with the LEGO Mindstorms kit from toy stores. Although both the Mindstorms software and LEGO RoboLab provide a drag-and-drop iconic interface that makes programming easy (it is possible to program without knowing how to read and write), Mindstorms is a little easier to use at first because it provides the metaphor of puzzle pieces that need to come together, but it can be limiting as well.

RoboLab has several levels of difficulty and a very high ceiling, so users can tailor the functions that are available to their personal programming skills and developmental stages (Portsmore, 1999). Thus, RoboLab has been the programming language of choice for educators worldwide. When using RoboLab in early childhood classrooms I suggest starting with the simple levels called Pilot, which can range in complexity and make it easy to manipulate the icons (see Figure 13). These levels also work well in classrooms with very few computers, because students are able to compose and download a program in very little time.

All program levels begin with a green light and end with a red light. Icons, representing actions, are strung together by a pink wire. In the

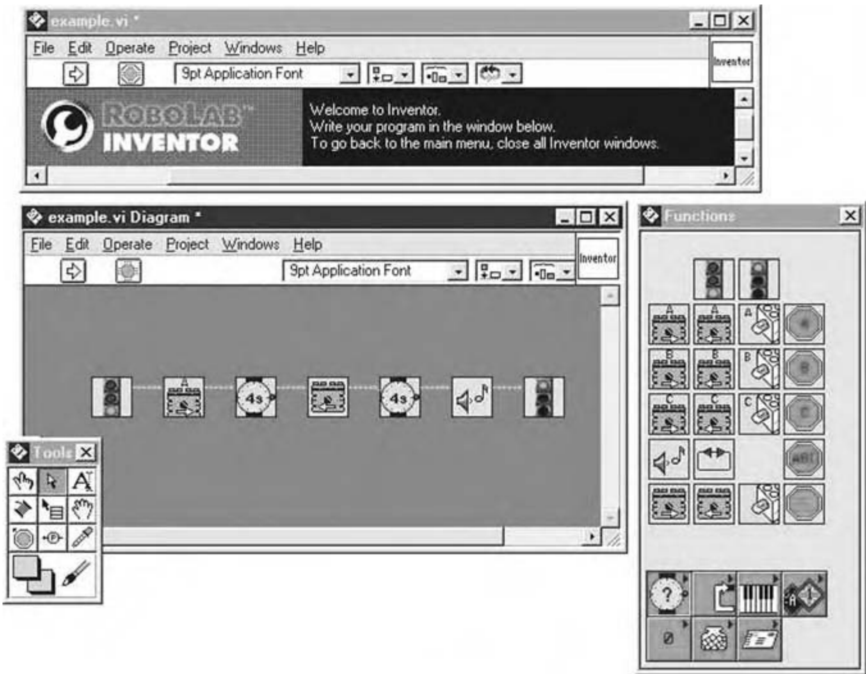


FIGURE 14. RoboLab Inventor level

Pilot levels, which range from 1 to 4, students select actions from a selection of images, and there is no need to use the pink wire. Later on, as children understand the concept of programming and they are able to better manipulate the mouse, it makes sense to switch to the Inventor levels, where students can assemble a program by selecting from a palette of multiple icons (see Figure 14). In the Pilot level, the program will always work—it might not do what children wanted but something will happen, because they are essentially picking from a limited list of behaviors. In Inventor, they are writing their own behaviors, and now they can run into standard programming problems and things might not work as expected. This then invites new possibilities for debugging and problem-solving.

This book is not intended to teach RoboLab or other programming languages for the LEGO Mindstorms robotics kit. At the end of the book, a list of resources and further references is presented. Chapter 4, "Designing the Environment: A Practical Guide," describes other commercially available robotics construction kits that can be used with very young children in the spirit of constructionism.

Teaching and Learning Powerful Ideas with a Robotic Manipulative

Robotics has traditionally been used to teach older children about engineering concepts by engaging them in teacher-directed challenges and competition. For example, robotics competitions such as the National Robotics Challenge (an open-platform robotics competition for middle school, high school, and postsecondary students) and FIRST (For Inspiration and Recognition of Science and Technology) provide a competitive forum for young people to solve an engineering design problem. As of 2005 there were over 100,000 students and 40,000 adult mentors from around the world involved in at least one of FIRST's competitions.

The concept of a competition as an event where robots must accomplish a given task (usually outperform another robot) is very appealing to some young people. However, others might be more interested in exhibitions rather than competitions. Although the use of competitive challenges is widespread in robotics education, research has shown that females do not tend to respond well to these teaching strategies (Turbak & Berg, 2002). Competitions emerge from a long-standing tradition of using challenges to help children discover concepts and develop specific skills. For example, a robotics curriculum is generally built around different design challenges that engage in step-by-step introduction to both engineering and computer programming.

Challenges and competitions might be useful in teaching specific concepts, but they may not always be appropriate in the early childhood setting. On the one hand, it is very difficult to reconcile the instructional challenges approach with notions of emergent curriculum based on children's own interest. On the other hand, the focus in early childhood on socioemotional development is more likely to engage children in collaboration rather than competition. Thus, it is important to identify an educational philosophy, such as constructionism, that is well suited for our work with young children and that understands the significance of robotic objects as carriers and incubators of powerful ideas, and not only as final products.

As stated earlier, robotics provides a platform for engaging children in exploring the man-made world, more specifically, the aspects of this world in which bits and atoms are integrated. This involves everyday objects such as automatic doors in supermarkets, motion-sensitive lights in yards, and automatic braking systems in cars. More complex objects are space shuttles, robotic surgeons, and bomb-finding robots.

Although all of these objects are interesting to study, a curriculum of powerful ideas is not built around objects. It is built around ideas.

Chapter 1 shows how powerful ideas afford new ways of thinking, new ways of putting knowledge to use, and new ways of making personal and epistemological connections with other domains of knowledge (Papert, 2000). Thus, objects such as the ones just mentioned are interesting because they can become carriers of powerful ideas about mechanics, sensing, control theory, and even artificial intelligence.

These powerful ideas afford new ways of thinking about everyday objects and also about disciplines such as physics and mathematics. For example, the gears in some of these objects invite children to think about powerful mathematical ideas such as ratios. When children are provided with opportunities to use gears in the design of their robots, personal connections with ideas such as ratio start to emerge. As schooling progresses, these ideas will be formalized through abstract equations, but the first concrete personal relationships with these powerful ideas will already have been established.

At the intersection of all these powerful ideas emerges the notion of technological fluency. This "content–process" powerful idea refers to the use and application of technology in a fluent way, effortless and smooth, as one does with language (process). It also involves the development of knowledge within the information technology domain and related areas such as physics, engineering, mathematics, and computer programming (content). Robotics construction kits provide a playful platform for developing technological fluency in an integrated way with other domains of the curriculum.

A technologically fluent person can use technology to write a story, make a drawing, model a complex simulation, or program a robotic creature (Papert & Resnick, 1996). As with learning a second language, fluency takes time to achieve and requires hard work and motivation. For example, to express ourselves through a poem, we first need to learn the alphabet. In the same spirit, to create a digital picture or program a robot, we first need to learn how to use the keyboard and to navigate the interface, how to use a Paint program and Word, or how the LEGO pieces connect together. These building blocks have come to be known as "computer literacy" or "technological literacy." However, skills with specific applications or products are necessary but not sufficient for children to grow in the information age, where new skills are constantly needed.

Although learning the alphabet is needed to write a poem, it is not enough. In the same spirit, knowing how to use software or robotics packages is not enough to become technologically fluent. As stated by the Committee on Information Technology Literacy in 1999, "the 'skills' approach lacks 'staying power'." Thus, regardless of the age or developmental stage of the child, technological literacy is a fundamental stepping stone toward technological fluency, but it should not be a goal in and of itself.

Technological fluency is knowledge about what technology is, how it works, what purposes it can serve, and how it can be used efficiently and effectively to achieve specific personal and societal goals. As of 2006, most states included engineering/technology standards in their educational frameworks (see Appendix A for a table comparing the state of the art of each state regarding these curricular frameworks).

Massachusetts is leading the nation in declaring that technology and engineering are as important to the curriculum as science, social studies, and other key subjects. For example, as early as 2001 the Massachusetts Science and Technology/Engineering Curriculum Framework mandated the teaching of technology and engineering for all students in grades pre-K–12. Although teachers have some freedom to engage their students in the discovery of powerful ideas, these days, what is taught in the classrooms is very much guided by state and federal curriculum frameworks that identify what each child should know.

Ioannis Miaoulis, president and director of the Museum of Science, played a key role in introducing engineering and technology in Massachusetts's K–12 frameworks and now, through the National Center for Technological Literacy, in taking it nationwide. He explains:

> The Federal Government has some learning requirements through the "No Child Left Behind Act" in the areas of reading, math, and soon science. Although it cannot mandate curriculum at the state level, it can mandate states to reach a certain level or standard of learning. For successfully introducing, in a wholesale way or in a national way, a new discipline like engineering, we need a strategy that works at two different levels: individual states need to include engineering when they write their standards; and any new standards that come out at the national level also should include technology and engineering. As states periodically rewrite their standards, they look at what the national standards look like. And if they see technology and engineering in the national standards then they may consider including them into their own standards. Helping at both the state and the national level is part of our efforts through the Center for Technological Literacy.
>
> However, if technology and engineering are in both the state and the national frameworks, but children do not get tested, teachers might

> decide to skip this content by using the following arguments: "There are too many things to do in the day and now you are throwing us another one!?" and "I am not an engineer, how am I supposed to teach engineering?" Of course teachers are not mathematicians, but they teach mathematics; they are not writers and they teach writing, and they are not historians and they teach social studies; so it is the same thing. But engineering and technology is something new and they have to learn it. So the ideal strategy to get it taught nationally, is to put it in each state's framework and test it. Because it may be in the frameworks but if it is not tested, it is not going to be taught. Of course, then we need to talk about what kind of testing and formal assessments are best and how to implement them so children can do more creative things such as building something, designing, or put together a portfolio. (personal communication, 2006)

Both state and national frameworks are constructed around powerful ideas. Table 1 shows how some of the powerful ideas encountered by engaging in the design of a robotics project relate to the curricular frameworks of Massachusetts. Although Massachusetts was chosen as an example because of its pioneering role, this is similar to other states in the United States and other countries that emphasize technology education.

Robotic manipulatives provide a venue through which to engage children in developing technological fluency (Miaoulis, 2001; National Academy of Engineering & National Research Council, 2002). They also offer a platform for project-based learning (Resnick et al., 2000) that promotes design processes such as iteration and testing of alternatives in problem posing and problem solving. By designing a robotics project, powerful ideas from different curricular domains can be integrated. Appendix B provides an example of how to develop a curricular web that integrates robotics with other disciplines. Last but not least, robotic manipulatives can motivate students to engage in learning complex concepts, in particular in the areas of math and science, even when they label themselves as "not good at" or "not interested in" either subject (Bers & Urrea, 2000). Table 2 presents examples of different curricula designed and implemented around powerful ideas in several early childhood classrooms, private and public, urban and suburban. A more complete description of the curricula can be found at the following Web site: http://www.ase.tufts.edu/devtech/projectslibrary/projectslibrary.html.

In the spirit of Piaget, robotic manipulatives provide opportunities for both little engineers and little storytellers to develop technological

TABLE 1. Engineering and technology standards in the United States in 2006. Table provided by Yvonne Spicer, National Center for Technological Literacy (NCTL), Boston Museum of Science

Science/ Engineering Concept	Definition	Massachusetts Curriculum Technology/Engineering Frameworks, Pre-K–5
Problem solving	Inventing a solution to a given problem	General design process
Brainstorming	Using creativity during problem solving	Demonstrate methods of representing solutions to a design problem
Design process	A sequence of steps that leads one through a problem-solving challenge	Identify and explain the steps of the engineering design process
Programming sequence	The specific order in which commands are arranged to ultimately perform a task	Identify and explain how symbols are used to communicate a message
Identify constraints	Recognizing the limitations of a given problem	Explain how design features would affect construction of a prototype
Prototyping	Constructing a model of the proposed solution to a problem for testing	Describe and explain the purpose of a given prototype
Materials selection	The act of identifying the most appropriate materials for creating a solution	Identify materials used to accomplish a design task based on a specific property
Energy transfer	Changing one form of energy into another	Describe how human bodies use parts of the body as tools, and compare that with animals
Forces	A push or pull that acts on an object	Identify relevant design features for building a prototype, such as size, shape, weight
Motion	A change of position of one body with respect to another body, frame of reference, or coordinate system	Compare natural systems with mechanical systems that are designed to serve similar purposes
Wheel and axle	A simple machine consisting of a rotating rod placed in the wheel's center, thus making it easier to move objects	Identify tools and simple machines used for a specific purpose

Science/ Engineering Concept	Definition	Massachusetts Curriculum Technology/Engineering Frameworks, Pre-K–5
Lever	A simple machine consisting of an arm pivoting at a center point to easily lift objects	Identify tools and simple machines used for a specific purpose
Gear	A wheel with teeth used to transfer motion	Identify and explain the difference between simple and complex machines
Friction	The force that opposes a desired motion due to the contact of objects	Explain how design features would affect construction of a prototype
Stability	The necessary property of structures to prevent failure	Identify relevant design features of a solution
Sensors	Objects that identify a change in the immediate surrounding environment	Describe how human bodies use parts of the body as tools, and compare that with animals
Feedback	The response of sensors to a change in the surrounding environment	Identify the five elements of a universal system model
Looping	A programming method used to create an infinite program so that tasks may be repeated	Identify and explain how symbols are used to communicate a message
Input and output	Terms used for information exchanged through a computer	Identify the five elements of a universal system model
Troubleshooting/ debugging	Identifying the error(s) in a computer program	Identify and explain the steps of the engineering design process

fluency, while respecting and engaging their own epistemological styles and ways of knowing the world (Bruner, 1986). Early childhood educators have long recognized the importance of this. In good early childhood education settings we can find books as well as building blocks. When using robotics, this should be kept in mind. It is not enough to adapt the challenge-based robotics curriculum developed for upper elementary grades. As in all other domains of early childhood education, when engaging children with technology, "epistemological pluralism," diversity in ways of knowing and approaching problems and ideas, should be respected (Turkle & Papert, 1992).

TABLE 2. Powerful ideas from engineering and technology as they relate to state curriculum frameworks

Powerful Idea	Curriculum Description	Relationship to Frameworks	Level	Developer*
Metamorphosis	The teacher introduced the concept of change through several aspects of the curriculum, with an emphasis on metamorphosis. After reading *The Hungry Caterpillar,* children sequenced the story and did dramatic play, movement, and art activities to explore change. They used the Mindstorms kit to make a robotic vehicle, representing the heart of the caterpillar, that would travel the journey of the "hungry caterpillar" on an already-designed road. Children would dress up the robot/heart with puppets representing its different life cycle stages.	Life sciences: study life cycles, recognize changes in animals and plants	Preschool: 3–4 years old	Iris Ponte
Cardinal directions	The children began by directionally navigating a map of their town and developing personal connections to the town. The class next researched historical landmarks of the town and wrote illustrated fiction stories about the town. Then they created a floor map of the town to scale and built and programmed a school bus that would navigate the town floor map and stop at different locations.	Mapping, scientific method, language, literature, writing, social studies, science and technology	2nd grade	Alaina Thiel
Magnetism	The teacher designed activities in which the children explored and discussed the properties of magnets. First, a preprogrammed car was used to test the strength of magnets. Then children designed their own vehicles to follow a path on their way to a magnet.	3rd-grade topic relating to technology strand	2nd grade	Nicole Notaro
Cause and effect	Meeting the interests of the classroom boys, the teacher introduced the Mindstorms kit to a group of children as a means of collaboratively designing and creating a fire engine with light sensors. The kit was also used with the girls in the class to develop a doll cradle with touch sensors. Manipulable icons were used to promote understanding of the programming language.	Cause and effect, community helpers, programming	Preschool: 3–4 years old	Ana Zamora

Shadows: light/ darkness, shapes, motion, relations	Within this teacher's Shadow curriculum, a child-controlled robotic car was used to carry puppets around the room as children traced the shadow's pattern of movement.	Language arts, math, science and technology, history/ social science, health, arts	Preschool: 3–4 years old	Eva May
Patterns	As the children explored patterns in life, space, and time, the teacher incorporated the design and creation of a robotic space rover vehicle. The children developed patterned programs for their vehicle and were challenged to identify other groups' patterns.	Physical science: motion; math: repeating patterns	Preschool: 4–5 years old	Jo-Ellen Rowley
Measuring speed: time and distance	Robotics was used to address children's inquiries about speed and measurement. Through the exploration of the RCX and touch and light sensors, the children developed a tool for measuring the motion of objects traveling on different slopes. The information was graphed in RoboLab and the children recorded their observations with words and pictures.	Scientific inquiry, cause and effect, measurement, programming, math vocabulary, patterns, data analysis, life and physical sciences, motion, senses, technology/ engineering	Preschool: 4–5 years	Maggie Beneke
Light as a source of energy	With a focus on principles of solar power, the goal of this activity was to create a robotic light-powered dollhouse featuring indoor lighting, moving parts, functioning appliances, and a battery dial measuring stored energy. Children built, explored, measured, and experimented with factors involved in the process of solar power.	Identify light as a form of energy, properties of energy	1st–4th grades	Russell Sargent, Brendan Sullivan, Alex Clark, Sarah Cochrane, Aram Mead

*Developers were all students in interdisciplinary courses that I taught in technology and education at the Eliot-Pearson Department of Child Development at Tufts University between 2001 and 2006. Participants in the courses were undergraduate and graduate students from a variety of departments, including Child Development, Education, Computer Science, and Engineering.

Although traditionally conceived as purely mechanical kits, robotic manipulatives can be inviting to both young engineers and storytellers if presented with the right educational philosophy and pedagogy. For example, whereas some children might make robotic creatures to enact a play, others might focus on building dinosaurs, lifting bridges, or racing robotic cars (Bers, 2007b). Some educational programs, such as Project Con-science in the Arlene Fern Jewish community school in Buenos Aires, Argentina, invited children to create "technological prayers," robotics projects that represent religious symbols of universal values. For example, a young boy and his father chose the value "awakening" or "call for reflection" and designed a LEGO-based Star of David. The young boy said:

> We built a "Maguen David," Star of David, as a symbol of our Jewish people and we programmed it to turn forever like the wheel of life and have flashing lights resembling candles welcoming the New Year. We also reproduced the sound of the shofar. It has three different tones that are supposed to awake us for reflection and atonement. (Bers & Urrea, 2000)

Although most uses of robotics have focused on promoting the teaching and learning of math, science, engineering, and technology, the experiences of both the Con-science and the Inter-Actions projects (Bers et al., 2004) show the potential of robotics to engage children in storytelling and exploration of identity issues (Bers, 2007b).

CHAPTER 4

Designing the Environment

A Practical Guide

Rather than stifling the children's creativity, the solution is to create an intellectual environment less dominated than the school's by the criteria of true and false.

—Seymour Papert (*Mindstorms,* 1980, p. 133)

This chapter provides initial guidelines to orient readers interested in exploring the use of robotics in early childhood. It is not intended to be a comprehensive how-to manual, but a first introduction to how to approach the work. As opposed to a prescribed set of rules for putting robotics into action, the chapter presents suggestions in four areas: designing the learning environment, obtaining further resources, curriculum starters with robotics, and engaging parents.

Designing the Learning Environment

We have learned about constructionism and have an understanding about developmentally appropriate pedagogy and philosophy for using robotics in early childhood. And we have learned about robotic manipulatives and their long-standing tradition in other learning manipulatives. How do we initiate our own work with robotics? We should start by actively designing the learning environment, not only by developing or adapting curricula. This section is organized around five different physical stations needed when designing a successful early childhood robotics learning environment: programming stations, building stations, design and art stations, floor space, and walls.

Programming Stations

In an ideal learning environment, there will be enough programming stations to accommodate every child, or at least every group of children working together on a project. However, this is not mandatory, because there are ways to develop successful learning environments even with one computer for the whole classroom. Programming stations need to provide ample space on the desk or table to accommodate the computer, the infrared tower, and the robotic construction itself. Because downloading the program to the robotic artifact is done several times during the duration of an activity, ample table space will prevent projects from falling down and breaking apart. Tables and chairs need to be accessible to children and be distributed in order to facilitate circulation. Working with robotics involves a collaborative experience, so there is a lot of moving around and gathering in front of computers. For that purpose, it is also suggested that there be multiple chairs at each computer to facilitate partner and team work. On a wall next to the programming stations it is always helpful to have a large poster displaying the icons of the programming language. It is also useful to have a white board for sketching programming flows, and to let the children experiment on the board with programming icons (see Figure 15). A projector, connected to one of the computers, is useful for sharing programming tips with the whole class. Shelves or drawers located out of reach of the children should have software boxes, manuals, and computer peripherals. A locked cabinet is useful for storing expensive documentation materials such as digital and video cameras and their corresponding supplies. Finally, it is important that all of the infrared towers point in different directions; otherwise it is easy for one group to download a program sent by another group. This is a common source of confusion in the classroom. Group A programs their RCX brick to go forward, but walks past Group B, who just hit "download." All of a sudden, Group A has a new program but does not realize it. This can be avoided if people turn off their RCXs when walking past computers and if the towers connected to neighboring computers face in different directions.

Building Stations

Robotics involves both programming in the computer and building with various materials. The building can be done with LEGO bricks or other items such as pipe cleaners, cardboard, and tape. Thus, building

FIGURE 15. Learning how to program using paper icons

stations are fundamental. These can be one or several large tables (depending on the size of the classroom and the number of children) located near the computer stations. Although some children like to build while sitting down, most of them prefer to build standing up. Thus, chairs should be positioned to accommodate both working styles. Next to the building stations there should be shelves for storing batteries, flashlights, extra pieces, and other tools that are commonly used with robotics. These shelves can be located in the upper part of the shelving unit, because they are primarily for teacher access. A special shelf, protected from the clutter and perhaps also located above the reach of the children, can be specially decorated and used as a display station for final projects once they have been completed, and before any public events. A different shelf, populated by empty bins and within reach of the children, can be used to temporarily store projects in progress. It is useful for each child or team to have a labeled bin to store her or his unfinished projects. LEGO parts can be stored in clearly labeled bins or buckets easily accessible to all the children. Bins of different sizes can be helpful for accommodating small or unique pieces. Near the building stations hang posters showing common building pieces and their names, as well as some basic construction tips.

Design and Art Stations

Children need to have table space where they can sit and use their design journals. For this purpose they also need to have ready access to drawing supplies. Robotics projects do not need to include LEGO parts only. Art and recyclable materials are very useful, and children tend to enjoy integrating them into their projects. Therefore, these materials, as well as glue, scissors, and tape, need to be readily available. Although in an ideal world it would be better to have different stations for the building, design, and art aspects of the work, with clearly expressed rules, such as avoiding gluing expensive LEGO parts like sensors or motors, activities can be combined using big tables with drawers or nearby cabinets to store the supplies.

Floor Space

Although much of the work with robotics happens on tables in the programming and building stations, the floor is the best place for testing. Floors without carpets are most useful because they do not cause traction problems. However, having a small carpet to unfold is always handy for technology circles. Floor color can make a big difference if using black tape so robots can follow a line by using light sensors. For example, a sensor might get "confused" on a speckled floor. However, it is not always possible to choose the type of floor in a classroom, so having a large piece of plain wood where the robots can be tested is always a good idea. Because at some point or another most robotics projects involve the creation of moving creatures, a car, a dinosaur, or a snow plow, I suggested having a minimum of 6 feet of space for forward- and backward-moving robots. Floor space is a useful element in a robotics learning environment. However, outside playgrounds or courts with concrete floors, weather permitting, or inside spaces such as corridors, can also be used for testing purposes and provide a change of scenery that children tend to enjoy.

Walls

Walls serve three very important functions in robotics learning environments: documentation, memory, and teaching. First, walls as spaces for documentation serve to illustrate the process of making robotics projects, through posters done by both children and teachers. For example, photographs of children's work as it progresses can be included. Second, walls serve as spaces for memory. Working with robotics always poses the challenge of having limited resources and therefore not being able to maintain intact robotic creations. Usually, after a project is completed it needs to be disassembled, even if this is heartbreaking for both the children who spent so much energy constructing it and the teachers who supported their work. Memory walls can be used to display pictures and short descriptions of the projects in a classroom. As the year progresses, memory walls start to fill up and serve an emotional function in allowing children to celebrate their past projects. Third, walls serve as teaching spaces for displaying posters with programming icons and diagrams describing steps involved in the building process, and for hanging chalkboards or whiteboards. In sum, wall displays vividly inform the students, teachers, parents, the school community, and visitors about the work happening with robotics technology in the early childhood classroom.

Developmentally Appropriate Robotics Construction Kits

Most of the work presented in this book uses the LEGO Mindstorms kit. This is the most widely used robotic manipulative worldwide. It provides the advantage of engaging children with a well-known material, such as the LEGO construction bricks, and engages them in exploring new possibilities by adding controlled movement to their LEGO creations. The LEGO Mindstorms kit can be purchased with two different kinds of software: RoboLab, which is sold by the educational division of LEGO to schools, and Mindstorms, which is sold in commercial toy stores. While Mindstorms offers a quick way to start programming, the power of the programming language is limited. RoboLab provides scaffolding elements and several levels to help beginners, such as the Pilot levels, to more advanced features in the Inventor levels. It also provides tools for data collection and analysis (Investigator level). Other software, such as Logo Blocks, also works with this construction kit. LEGO has made available the source code, so computer scientists and engineers have played with it and developed their own programming languages (from C to JAVA). These are not commercially available, do not provide technical support, and in the majority of cases, require advanced programming skills. Although the LEGO Mindstorms Robotics Invention

System with its RCX brick is the most popular robotics kit, other robotics kits exist in the market. However, most of them are targeted for middle school or high school students.

- The HandyCricket, which also evolved from the earlier MIT "Programmable Brick" and the Handy Board, is a tiny, programmable computer (about the size of a 9-volt battery) that can directly control motors and receive information from sensors. It can be programmed using "Cricket Logo," a simplified version of the Logo language. More information can be found at http://handyboard.com/cricket/about/
- The Vex Robotics Design System, developed by Innovation First and Radio Shack, has more than 500 parts and more than 20 accessories and can be programmed with easyC, a graphical variant on the C language used by professional programmers. Although it has substantially more power than the Mindstorms kit, construction and programming take a fair amount of time and dexterity. More information can be found at http://www.vexlabs.com/
- Machine Science, a nonprofit organization dedicated to supporting hands-on engineering programs for young people, also provides several project kits. These are very open systems, with children building their own circuits and sensors. See http://www.machinescience.com/
- Microbric is an electronic construction kit based on the construction style/concept of both LEGO and Meccano. It allows users to build complex customized electronic devices. Microbric's I-bot is targeted for elementary and middle school children. It is a small, modular, easy-to-use robot that can be put together in stages and controlled in a number of ways. For example, children can use barcodes to teach I-bot how to respond to the TV remote, and they can also write their own programs. See http://www.microbric.com/ibot/
- The Boe-Bot from Parallax can be programmed using Microsoft Robotics Studio. See http://www.parallax.com/
- OWI Robotics offers different programmable robotics kits. See http://owirobots.com/
- RoboNova is a humanoid robot that can be programmed. It is available as a kit, so students can build their own robot, or as a preassembled, "RTW" ("ready to walk") instant robot. See http://www.lynxmotion.com/Category.aspx?CategoryID=91

- IRobot Create is a programmable robot, preassembled to facilitate the development of new robots. Robot developers can program behaviors, sounds, and movements, and can even build on other electronics. Computer programming experience is required. See http://store.irobot.com/shop/index.jsp?categoryId=2597845
- GEARS Education System. The GEARS-IDS Invention and Design System provides tools for teachers to create engineering and robotics challenges in their own classrooms. See: http://www.gearseds.com/
- LEGO Mindstorms NXT. This new kit will replace the RCX in 2009. However, the latest version of RoboLab offers upgraded RCX features as well as the ability to program the NXT at all levels (Pilot, Inventor, Investigator). LEGO Engineering provides educators with resources to aid in migration of technologies including news, activities, and a database to access information. See http://mindstorms.lego.com/

Most of the robotics construction kits mentioned above offer different technological platforms for building and programming robots. However, in contrast to the Mindstorms kit, most of these focus on older children and require teachers to have a working knowledge of engineering and electronics. How about young children? What other options besides the LEGO Mindstorms kit and the RCX brick are available? In the tradition of the first "programmable bricks" at the MIT Media Lab and the Mindstorms kit, PicoCrickets is specifically geared for younger children and novice teachers. Whereas Mindstorms is created for making robots, PicoCrickets are designed especially for making artistic creations that can behave in the world. PicoCrickets are based on research of the Lifelong Kindergarten group at the MIT Media Laboratory and are sold through the Playful Invention Company (PICO). More information can be found at http://www.picocricket.com

The PicoCrickets are tiny computers, smaller than Programmable Bricks, so they are well suited for projects that need to be compact and mobile (such as electronic jewelry) and can embed in children's physical creations. PicoCrickets can control not only motors but also multicolored lights and musical devices, so children can use PicoCrickets to build more artistic and expressive projects involving light, sound, music, and motion. For example, a young person might create a cat using craft materials, and then add a light sensor and a sound-making device. She could write a program (using the PicoCricket's easy-to-use graphical programming language) that waits for the light sensor to detect someone petting the cat, and then tells the sound box to play a meowing sound. Or one can use craft materials to create an interactive garden, with flowers that dance and change colors when you clap your hands (Resnick, 2006).

A different robotics kit for young children is Roamer from Valiant Technology. Based on the first Logo turtle, Roamer is a floor robot that moves around the room following a given set of instructions. Instructions are entered by pressing the buttons on the top of the device, and the robot moves as instructed. Roamer has simple graphic buttons that can be pushed in a series of commands that allow Roamer to be controlled by the young child. Roamer can go forward, go backward, turn at specific angles, sing, and draw. See http://www.valiant-technology.com/us/pages/roamer_home.php

Engaging Parents

In Part I of the book I addressed the importance of teachers supporting parents in their work with technology with their children. In this section, I suggest four different ways in which this can be done: (1) parents working with their children at home, (2) parent volunteers at school; (3) after-school models of parent–child robotics workshops and clubs, and (4) parents as liaisons with industry and academia.

Parents Working with Their Children at Home

Teachers communicate with parents about the math and literacy curriculum by sending letters home and suggesting family activities to complement what is happening in the classroom. In the same way, they can include work with technology. For example, it might be important for the teacher at the beginning of the year to get a sense of what kind of technology children are using at home and, for example, she or he could ask families to complete a survey. The teacher can also engage families in collecting data about the simple machines and the electronic devices they have at home and share it in class; or each week the teacher can assign a different child or family to do research about how a robotic object in their house or town works.

Parents Volunteering in the Classroom

In the United States there is a long-standing tradition of inviting parents to volunteer in the classroom. Some volunteer on a weekly basis and have assigned roles, such as helping children with academics or supervising lunchtime. Others may volunteer once to share a tradition or celebration from their homeland and culture. Engaging parents in technology-related activities is a wonderful way to complement the knowledge of the teacher and to provide more support in the classroom. As mentioned earlier, many of today's parents (and sometimes grandparents as well) are computer scientists and engineers, or have jobs related to the information technology industry. Teachers need to learn how to take advantage of these tech savvy parents. These parents can come as special guests to share a specific aspect of their job. Or they can be "on call," and volunteer when technology-related activities are happening in the classroom. However, sometimes having many parents with different levels of expertise and different visions about what learning and teaching should be can be difficult. Thus, it is important to set up guidelines for how to work with young children and provide parents with basic information about how young children learn and think. For example, conducting an evening for training volunteer parents is something that has worked very well in my own experience working with parents in the classroom.

After-School Activities

In many school districts we have found that parents, after working in the classroom with robotics-based activities, see the benefits and gain confidence in their own teaching potential. They organize their own robotics clubs and parent–child robotics workshops after school. Because the materials are already in the school, organizing these types of activities is not hard. Many of the Web sites listed in this chapter provide information about how to start this work.

Regardless of the choice of how to involve parents in the work with technology with children, either at home, in the classroom, or in after-school settings, it is important to remember that different families have different interaction styles, some which are more conducive to learning than others. For example, some parents initiate and direct the work with the child, some put the child in charge, and some parent–child dyads seem to enjoy taking turns being in charge of their work. It is not easy for all the parent–child dyads to become comfortable with each other in new roles as both teachers and learners. In most of the cases, it is the parents, and not the children, who have the most difficulties adjusting. It is often anxiety-provoking for a parent to have to learn something new and, at the same time, help his or her child with his or her own learning. Based on research on Project InterActions, this is true regardless of the previous level of comfort that parents have with technology (Beals & Bers, 2006). Some parents worry about getting it right, and in some cases, this attitude can get in the way of working with their children. To address some of these concerns, I start my own work with parents by giving them the following guidelines:

- This is a learning experience. We are all exploring together.
- Families have different ways of working together. Find a way that works for you and your child.
- Learning new things is hard . . . sometimes it is harder for adults than for children.
- Learning about technology can be very frustrating and anxiety-provoking.
- Are you passing your own anxieties to your child?
- Don't worry, nobody gets it right the first time or even the tenth time. In fact, there is no "right" way.
- Adults and children can learn in very different ways.
- We are not expecting you to have perfectly working projects.
- Play with the materials and the ideas. You don't have to get it right.
- Success can mean different things for children and for adults.
- Ask questions (to your child, to us, to other families).
- Talk to each other, look at each other's projects, copy the things that you like . . . you are not cheating.
- We learn by doing and by making mistakes.
- Have fun and relax! This is a time to spend together with your child.

Parents as Liaisons with Industry and Academia

Parents can play an important role in setting up connections with both industry and academia to support technology and engineering education. Many industries that rely heavily on a workforce with math, science, and engineering knowledge are significant supporters of K–12 education. Some have generous grant programs in place such as FIRST, Engineer's Week, Explorer Scouts, and so forth, and others encourage employees to volunteer to work with students in the local community as mentors or tutors. Several companies, like Lockheed Martin, Intel, Rocketdyne, and National Instruments, have developed programs that help K–12 teachers to learn more about math, science, and engineering through courses and summer workshops. National

Instruments also provides year-round classroom support to teachers via employee volunteers. TechCorps, a national nonprofit, provides similar support by pairing technical volunteers with K–12 students and/or classrooms. The National Science Foundation also has a strong commitment to placing experts in the classroom through its GK–12 program, which provides tuition waivers and stipends to graduate student fellows pursuing advanced degrees in science, math, or engineering in exchange for the students spending 15 hours per week in K–12 classrooms. Many undergraduates in technical fields volunteer their time in school and after-school settings (Bers & Portsmore, 2005).

Placing college students or adult professionals in the classrooms provides positive outcomes for all involved: it (1) supports teachers in their work with technology with the children, while also helping them develop their own skills and confidence; (2) provides different avenues for educating children early on about technical disciplines; and (3) provides a window for college students and professionals to learn more about the education system and its challenges, allowing them to become more fully engaged civic citizens. Although teachers might lack the time and resources to investigate the myriad of existing partnership programs, parents can play an important role in information gathering, grant writing, and advocacy.

Resources

This section provides Web links that are useful for working with robotics in early childhood. Most of these sites have age-appropriate activities for young children, as well as resources for parents and educators.

Web Links

http://www.ceeo.tufts.edu/

The Web site for the Center of Educational Engineering Outreach (CEEO) at Tufts University. It describes the vision, goals, and programs of the Center and how one can get involved.

http://www.ceeo.tufts.edu/robolabatceeo/

The Web site for the RoboLab programming language at the CEEO. It provides useful tips and curriculum resources (organized around curricular frameworks) for parents and schools.

http://www.legoengineering.com

This Web site provides curricular projects, community support, and general help with LEGO Engineering.

http://www.mos.org/nctl/

The Web site of the National Center for Technological Literacy at the Boston Museum of Science provides K–12 activities, resources, and professional development opportunities for engineering and technology education.

http://llk.media.mit.edu/

The Web site of the LifeLong Kindergarten Research Group directed by Mitchel Resnick at the MIT Media Lab provides links to academic papers and innovative research projects developing technologies for children.

http://www.ase.tufts.edu/devtech/

The Web site of the Development Technologies Research Group, which the author directs at the Eliot-Pearson Department of Child Development at Tufts University, provides a link to the Early Childhood Robotics Research Program, as well as links to academic papers on early childhood and technology.

Curriculum Starters

This section presents six examples of curricula for introducing young children to the concepts of building and programming. The following activities using the LEGO Mindstorms robotics kit are reprinted with special permission from LEGOengineering.com. They are all well suited for early childhood, K–3.

The Tower

The goal of this activity is to design and construct a tower that is at least 4–6 inches high. The tower must be strong enough to withstand the weight of a stack of books.

Topics

Building, Sturdiness & Familiarity with Different LEGO Pieces

Subjects

Engineering

Building Hints

Using beams and connector pegs will help students create a sturdy structure.

Testing

Test the tower's stability by performing two tests:

1. Stack books on top of the tower
2. Stand on it

Classroom Procedure

1. Discuss sturdiness with the students and why certain structures are sturdier than others.
2. Students can work individually or in groups as long as there are enough beams, bricks, axles, and connector pegs. Each tower should be 5–6 inches high.
3. Students should build a tower that is sturdy enough to support several textbooks and/or the weight of a person.
4. Have the students test the structures and redesign as they work.
5. Spend 5 minutes at the end of the lesson discussing the walls that the students built. Have them assess which techniques worked and which did not work.
6. Be sure to exploit weaknesses so that in later exercises they will not make the same mistakes.
7. Point out the advantages of interweaving pieces, adding connector pegs and axles for support, and making supports wide for greater balance and strength.
8. Students can fill out an engineering journal.

Snail Car RCX

The goal of this activity is to design and construct a snail car capable of traveling extremely slowly. The cars compete in a snail race with the last car to cross the finish line crowned as the winner.

Topics

Gears, Gear Trains & Friction

Subjects

Math, Science, Engineering & Technology

Programming Themes

Motor Forward

Related Math & Science Concepts

Gears, Wheels and Axles, Acceleration, Velocity, Friction, Torque

Materials

RCX Car
Gears

Building Instructions

Build an RCX car that utilizes a series of gears and axles.

Programming Instructions

Using RoboLab Inventor 2, program a car to run forward for 20 seconds.

Mountain Rescue

The goal of this activity is to design and construct a car that is able to climb a steep incline.

Topics

Gears, Friction, Torque & Speed

Subjects

Math, Science, Engineering & Technology

Programming Themes

Motor Forward

Related Math & Science Concepts

Gears, Torque, Wheel and Axle, Acceleration, Velocity, Friction, Force

Materials

RCX Brick
Gears
Ramp

Building Instructions

1. Assemble a ramp with multiple degrees of slope.
2. Build a car that is capable of climbing the ramp. The car should be capable of climbing a steep incline without slipping. This vehicle is built for power, not for speed.

Building Hints

Gearing down will slow down your car but will supply more power for climbing.

Programming Instructions

Using either RoboLab Pilot 1 or Inventor 1, program a car to run for 20 seconds.

Classroom Procedure

1. Set up the ramp that will serve as the mountain. You can use a piece of plywood as the ramp and prop it up on things of different heights to have varying steepness.
2. Students will design and build vehicles that are intended to climb steep hills. They will have to incorporate gears into their design to increase the torque.
3. If students are not familiar with gears, give them an overview on gearing up and gearing down.
4. Students should build and program their cars and then test them.
5. Have the students drive the cars up the ramps as a group. This can lead to a discussion about what works well (e.g., rubber tires) and what does not work (e.g., smooth, plastic wheels).

Scavenger Hunt RCX

The goal of this activity is to use an RCX brick and a light sensor to collect data about the light conditions of the room. Can children find light sensor readings in the range of 0–30? 60–90? 90–100? Draw conclusions and make generalizations about light intensity in the room.

Subjects

Math & Science

Topics

Light Sensors, Graphing, Data Collection & Analysis

Programming Themes

Light Sensor Data Collection

Materials

RCX
Light Sensor

Building Instructions

Attach a light sensor to the RCX and wire to an RCX input.

Programming Instructions

1. Using RoboLab Investigator Program Level 1, program the RCX to collect a light reading every second for 10 seconds.
2. Collect readings. Walk around the room in order to draw conclusions and make generalizations about light intensity in the room.
3. Upload your data. Plot your results.

Classroom Procedure

1. Students should attach a light sensor to an RCX.
2. This is a great introductory activity to introduce Investigator. Students will use a light sensor to collect data about the light conditions in the room.
3. Discuss results of data collection. Which values were difficult to find? Why do you think this was true?
4. Allow students to experiment with uploading up to four sets of data. Demonstrate how to change the color or type of graph.
5. Present the challenge of trying to find a range of light readings. For example have them look for readings in the following ranges: 0–30, 31–60, 61–80, and 81–100.
6. Next, they should open Investigator and program their RCX to take light data every second for 10 seconds.
7. Have students collect the data and upload the results.

Activity Extension: Challenge the students to keep their light readings within reading levels between 50 and 70.

Amusement Park Ride

The goal of this activity is for students to design and construct an amusement park ride.

Topics

Building & Programming

Subjects

Engineering & Technology

Related Math & Science Concepts

Forces, Structures

Materials

RCX Brick
Assortment of LEGO Pieces and Sensors

Building Instructions

Design an amusement park ride that imitates a real amusement park ride.

Programming Instructions

Select appropriate software for the RCX used in the structure and program as necessary for the design of your amusement park ride.

Line Follower

The goal of this activity is for students to design and construct an RCX car and program it to be able to closely follow a line. Don't let your car stray from the road by using light sensors only.

Topics

Light Sensors, Turning, Gearing & Friction

Subjects

Science, Engineering & Technology

Programming Themes

Motor Forward, Wait for Light/Dark, Jumps/Lands

Related Math & Science Concepts

Gears, Wheels and Axles, Acceleration, Vector Quantities, Velocity

Materials

RCX Car That Can Turn
Solid Colored Floor
Tape (Opposite of the Floor)

Building Instructions

1. Assemble two motors together.
2. Attach the motor assembly to an RCX.
3. Add wheels, skid plates (or bent arm beams), and a bracket to the car.
4. Attach a light sensor to the bracket and RCX. Wire the motors.

Building Hints

- Using a skid plate instead of two front wheels helps reduce friction.
- Friction reduction allows for ease in turning.
- Gearing down will slow down your car and make tighter turns.
- The light sensor should be facing down and as close to the floor as possible.

Programming Instructions

1. Using RoboLab Pilot 4 or RoboLab Inventor 4, program the car so that one motor runs until it sees light and then the other motor runs until it sees dark.
2. The car should be able to follow a line (either light or dark) and be able to turn both left and right.

Classroom Procedure

1. Students will use an RCX car and a light sensor to make a line follower. The car should be able to turn.
2. Discuss design criteria before they start building. Because the cars will need to turn, the design will be different from that of a car that just drives forward.
3. Completed line followers can start by using the easy course (slightly wavy line) and move on to a harder course (line with a right angle).
4. Students can fill out an engineering journal to document their project.

VIGNETTE

Building Boston Together

Local History Through Robotics

Rebecca Merino *and* Kevin Staszowski

Becky Merino completed her undergraduate degree in elementary/special education and her graduate degree in Exceptional Children at The University of Delaware. This is her ninth year of teaching elementary school. She is currently a first- and second-grade teacher at Eliot-Pearson Children's School, an inclusive laboratory school associated with the Child Development Department of Tufts University. Her classroom team consists of herself, a graduate teaching assistant, and two one-to-one instructional aides. She has always looked for ways to incorporate engineering and science into hands-on curricula for children, and has appreciated the opportunities presented by LEGO robotics.

Kevin Staszowski received his undergraduate degree in environmental engineering from Tufts University and, after working for 2 years with an environmental consulting firm, returned to Tufts University for his graduate work in Child Development. He is currently a project manager with the Center for Engineering Education Outreach, directing a National Science foundation grant that matches graduate students in engineering disciplines with teachers in the Boston area.

This is the story of collaboration between a teacher and an engineer. It is our hope that this work can inspire others to find partnerships with local universities or industries.

During the 2005–2006 academic year, we decided to use robotics technology in a first- and second-grade combination class at the Eliot-Pearson Children's School. We did not want the technology to stand alone. We wanted it to support the curriculum and to serve the purpose of integrating different curricular areas. But finding an overarching, interesting theme for our project was troublesome, as the class had such varied interests. One topic that seemed captivating to all was the local Massachusetts geography, specifically the geography of the nearby capital city of Boston. So we asked our students, "What is so great about Boston? People come here from all over the world. You live right next to it, but do you know what makes it special?"

Our long list of responses included sports teams, famous museums, famous Boston residents, and finally, the Freedom Trail. Everyone indicated that the Freedom Trail was important, but very few children knew what the Freedom Trail actually was. So, as a class, we decided to get to know Boston better by exploring sites on and around the Freedom Trail. Although we chose this as the focus of the class project, we wanted to encourage children to make their own personal connections to our city. We hoped that, with the variety of historical sites along the Freedom Trail, each child would find something of specific interest to explore further.

First, we gave the class large close-up photographs of a variety of historical buildings and sites to sketch in their "Boston Sketchpads." This drawing activity helped them to tune in to the smaller details of the Freedom Trail and to begin to form a personal connection with the places they would soon see. With their curiosity piqued, the class followed this activity by taking a subway into Boston to experience some of the historical components of the city. We rode the subway in, took a DUCK (amphibious vehicle) tour of the streets and waterways, had lunch in the cafeteria of the Prudential Center, and fed the pigeons alongside the reflections of Trinity Church at the John Hancock Tower. At school, the children also began working on sections of a 6 × 6-foot map of Boston and the Freedom Trail as a way of remembering their journey through the city. This work helped set the foundation for introducing robotics in an integrated way with the emergent curriculum.

We decided that building models would help foster ownership of the sites that the children were studying. Using LEGO bricks would add an opportunity for children to explore and further their skills in technological design and problem-solving. It would also add a more engaging way for children to recreate what was important to them. It was important to us that LEGO be a component of the curriculum without taking over the content.

Children voted for the sites they were most interested in, and small groups were formed, each studying one or two stops on the Freedom Trail. Each group met with a team of undergraduate engineering student assistants to brainstorm and sketch ideas for building their models. Within this brainstorming session, children also found ways of adding robotic LEGO components to their buildings. These initial sessions helped children tune in to details they could replicate and emphasize with LEGO bricks, especially as each building group took tours of their individual sites. Ultimately, many of those initial ideas changed as the children studied their sites in greater depth, but children understood that planning and discussion were precursors to building.

The projects took shape over the course of 2 months, during which we had weekly 60-minute building sessions. The first few meetings were used to teach the children the basics of building and programming. After this orientation period, they began building the structure of their projects out of recycled materials like cereal boxes and egg cartons. The robotic LEGO bricks were used to create the kinetic portions of their projects, and much of the free-building time was devoted to creating and programming the LEGO Mindstorms "additions."

Because there was a balance between building with recycled construction materials and with LEGO bricks, children were able to stay engaged and rarely felt frustrated. If they were waiting for teacher support for a specific component, they could work on the structure or artistic elements of their building. Everyone had the opportunity to work with LEGO bricks, and some children chose to engage deeply with the robotic LEGO bricks. Other children decided go further with different interests such as learning and writing additional facts or measuring and cutting cardboard to create buildings. Part of this process included the children also negotiating and coordinating how the robotic and nonrobotic parts of the project would fit together. When the children were not in building sessions, they continued to work on other components of the project such as sketches of their sites in Boston, reading books in class, and ongoing discussions about the challenges and successes they met with while working and building together.

Although LEGO bricks were just one part of a large project, they showcased the small details children focused during their studies, and thus became a very powerful tool for sharing what they learned. They also fostered communication and collaboration among the groups as the children needed to make shared decisions, solve building issues, and have the whole piece come together. Finally, they added a new technology to old history, so students could do more then "spit back" facts they had learned. They could present these ideas in meaningful and novel ways, showing each child's personal connection to Boston.

The Freedom Trail

We will describe the design process that one of the groups went through to recreate the Old North Church and the Copp's Hill Burying Ground. We expected the group to focus in on the two lamps hung in the Old North Church—as LEGO lights were something familiar to many of the children. The tower in the Old North Church was where, during the American Revolutionary War, Robert Newmann was to light one lantern if the British soldiers were marching on Lexington by land and two lanterns if the British were arriving by river. We also thought the group might work on creating a clock or church bell for this portion of the project. Instead, the group focused on another bit of trivia that we were unaware of—the man (Robert Newmann) who lit the lanterns in Old North Church had to jump out of the building's window to escape the British loyalists. The idea of a LEGO figurine flying out the window was very funny to the group, and we worried that the project would be too distracting. However, the group worked diligently to design a system to fling the figurine out of the Old North Church. The children actively engaged with the Mindstorms programming language instead of just using a construction-based solution, which is more typical for this age-group. Even with the programming solution, the group also went through a genuine redesign process when they found that their catapult stopped working properly when installed inside the Old North Church.

The Copp's Hill Burying Ground is the second oldest cemetery in Boston and is the resting place for many famous Boston natives. Rather than focus on the historical aspects of Copp's Hill, the group turned their attention to making the site creepy with marching LEGO skeletons. The children realized that marching LEGO skeletons would be very difficult to build, but—through brainstorming—they found a novel way to fulfill their idea for the project. Instead of making the skeletons travel across a static graveyard, the children decided to put stationary skeletons on a moving graveyard. This solution allowed the group to construct most of the Copp's Hill Burial Ground with recycled materials and use the LEGO bricks for the small portion of the project that needed to be motorized.

Our semester-long project culminated in an "art show" that was shared with the entire school and our families. Although it was called an art show, it was a chance for children to showcase their ongoing learning. Our art show opening began with a "DUCK Tour" of the

Freedom Trail. Children who finished their group project early or who wanted to work more with LEGO Mindstorms had a chance to build a LEGO car, which they covered with a paper DUCK boat. They programmed it to make stops on our 6 × 6-foot map of the Freedom Trail. When it hit a stop, the children who studied that site shared their construction, putting their robotic special effects into action. Laws popped up at the State House while the Swan Boat glided through the pond in the park. Tightrope walkers balanced at Faneuil Hall while the grasshopper on the roof spun around in frantic circles. The man who lit the lanterns came flying out the window, and the skeletons in Copp's Hill Burying Ground awoke. Paul Revere's house lit up, and he rode his horse to warn the troops. Later that month we culminated the project by visiting the last sites on the Freedom Trail: Bunker Hill Monument and the USS Constitution. We then ate lunch at the Warren Tavern (where Paul Revere used to eat) and had a lemonade toast to our exciting adventures and successful study of Boston!

VIGNETTE

Engineering by Design

Merredith Portsmore

Merredith Portsmore is a doctoral student in the Mathematics, Science, Technology, and Engineering Education program at Tufts University. She is also a program manager at Tufts Center for Engineering Educational Outreach for LEGOengineering.com, a Web site that provides resources for educators using LEGO Education products, and the STOMPnetwork.org, a network of engineering outreach programs. Her dissertation research focuses on engineering design in early elementary classrooms.

One rainy October day in a first-grade classroom during indoor recess, I saw Sam and Evan eagerly get out bins of wooden blocks and math manipulatives (pattern blocks) to build elaborate castles with towers and secret passageways. Katie, Sarah, and Sasha also got out bins of blocks to build houses for small plastic colored bears. Houses and towers were built and elaborately extended across the entire carpeted meeting area.

Blocks and the block corner are popular staples in early elementary classrooms. But thus far, we haven't put too much effort into capitalizing on young children's passion for building and designing. We can see from children's interest and proficiency with blocks that this could be a prime time to expose children to engineering design. The engineering design process introduces students to the ways of thinking involved in creating a product or process that addresses a need or problems. Ideas of posing a problem, research, planning, developing a prototype, testing, redesigning, and sharing solutions are all involved in engineering design. The design process, like the scientific method, gives students another tool for thinking and helps them engage with the world around them. In today's modern technological world an understanding of how to make and design things is as important as knowing how to obtain information and test hypotheses.

Tufts University's Center for Engineering Educational Outreach (CEEO) is dedicated to improving engineering in K–16. Although it is easy to see how engineering education can be addressed at the upper levels, engineering in early elementary school can be a challenge. I am incredibly interested in the early part of education because students are so interested in learning. Moreover, educators and school systems seem to have more flexibility in their curriculum and time in this age range. The following paragraphs describe one way of bringing engineering into early elementary school classrooms in a way that is meaningful, includes actual engineering concepts, and is age appropriate.

Engineering by Design in First Grade

A key focus of the existing engineering curriculum for young children developed at the CEEO is developing engineering readiness. We believe this is achieved through exposing students to the engineering design process and developing their facility with LEGO materials. The curriculum piece that best demonstrates the approach is "Engineering by Design," which features student activities that range from building sturdy walls to creating snow plows and their own transportation invention. The curriculum is targeted at first and second grades (6- to 8-year-olds) and was developed by first-grade teachers in cooperation with graduate and undergraduate students, including myself, at the CEEO. The teachers involved have been using this curriculum in their classrooms for several years, and the unit has received thousands of downloads via the Web. See http://130.64.87.22/robolabatceeo/k12/curriculum_units/Engineering%20by%20Design.pdf.

I have been using the unit extensively as the backbone for my dissertation research over the past 3 years, teaching 16 weeks of activities based on Engineering by Design in multiple first-grade classrooms. Activities are offered for 1 hour each week, during which I am principal instructor, assisted by the classroom teacher and volunteers or graduate students. The time I spend in the classroom is typically referred to as LEGO Engineering time. We talk about what an engineer does and read stories to better understand what engineers are involved in designing. We talk about the difference between designing something and making it, and we discuss the construction workers and manufacturers who actually make engineers' designs come to life.

Groups of two students typically work with one set of materials on engineering projects that incorporate the basic LEGO pieces as well as mechanical elements like gears, pulleys, and a motor. Sometimes little fingers have trouble with some of the smaller pieces, but in general I have found that students are able to have great success with the materials (with a little help attaching a pulley or separating small pieces).

Getting Started: From Play to Design

The initial activities in the curriculum are designed to help the pairs learn to work together and to differentiate LEGO Engineering from LEGO play. LEGO materials are heavily associated with play, so it's important to make a formal distinction. If possible, it's also best to have separate LEGO materials for planning and for engineering so both activities can easily flourish.

Students first learn the names of the pieces and their dimensions. This enables the classroom to have a common language for talking about materials. We encourage students to ask for pieces using their proper names ("Can I have a 2 × 4 brick?"). In the very first task each student is given ten 2 × 4 LEGO bricks. Each pair must build a single construction from 20 pieces. Strategies for compromising and cooperation are discussed. Students also complete a "Final Report" that consists of a drawing of what they have made and reflections on whether or not they were good partners and enjoyed the activity. This helps students practice in a low-stakes setting at being good partners and understanding how LEGO Engineering time will work.

The Engineering Design Process

A simplified version of the engineering design process found in the Massachusetts Engineering/Design frameworks guides all of the activities in the Engineering by Design activities. In the initial activities (like building a sturdy wall) the students only use two or three steps (such as test, redesign, and share). As they progress through the activities, they are introduced to more and more steps. The steps are also heavily scaffolded. In the beginning, the problem and tests are clearly defined by the teacher, but as they progress through the curriculum the students perform more of the steps independently and make their own choices.

Once students have a basic knowledge of the pieces and some strategies for working together, their next task is to create a sturdy wall. They look at real walls and study the building technique of overlapping bricks. Their wall must be able to withstand a drop test from the height of the students' knees. Typically students are familiar with the construction method of stacking LEGO bricks but are new at considering how the stacking might impact the performance of their wall. This activity also introduces students to the concept of testing and redesigning. Testing and redesigning are generally unfamiliar to young children. Young children tend to build something once and declare it done, and then move on to something else. However, testing and redesigning is an important part of engineering design and therefore needs to be introduced as part of the classroom culture of LEGO Engineering time. To do this, I clearly define the tests that a construction will have to go through and pass before the students can move on to another challenge. I always emphasize that almost everyone's construction will fail the first time, and it will probably fail many, many times. ("It could fail 5 times, it could fail 50 times, it could even fail 100 times, and that doesn't mean you aren't a great engineer.") When we share the children's final constructions we celebrate perseverance ("Did you know that Sarah and Steve's failed 10 times before they got it to work?"). While the children are testing, the educators try to have the students reflect on the outcome of their test ("Where did your wall break when you dropped it? Why did it break? How could you keep it from breaking in the same place again?")

"A Chair for Mr. Bear" is the first full engineering design problem students engage in. The students are shown Mr. Bear (a floppy stuffed animal) and told that he needs somewhere to sit. They are presented with the constraints that whatever they build needs to keep him seated upright and prevent him from falling over to the left or right. The students are asked to draw plans for their chair and to discuss them with their partner. Additional pieces and construction techniques are introduced. The constructions created by students are vastly different. Some pairs are able to build sophisticated symmetric chairs, while others struggle to construct a simple cohesive chair (see Figure 16).

As they continue through the curriculum, more of the engineering design project is presented. When the students are presented with the problem of moving snow (typically Styrofoam peanuts and wet paper towels), they start to do some research. I collect pictures of snow moving devices (snow plows, front loaders, snow blowers) into a packet that they can review. They draw plans of what their snow mover will

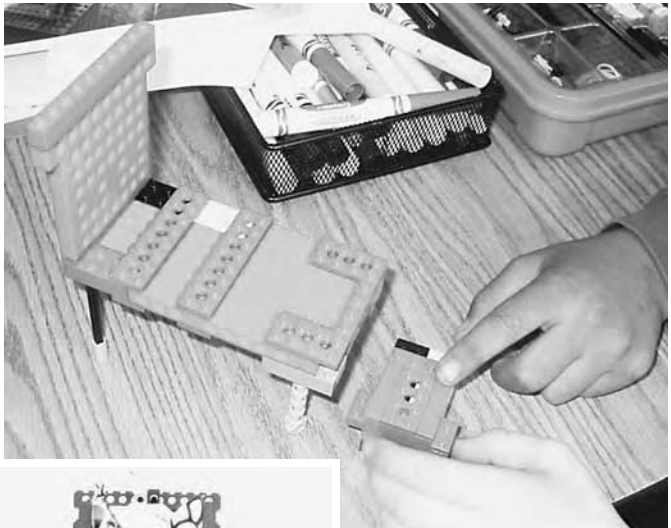
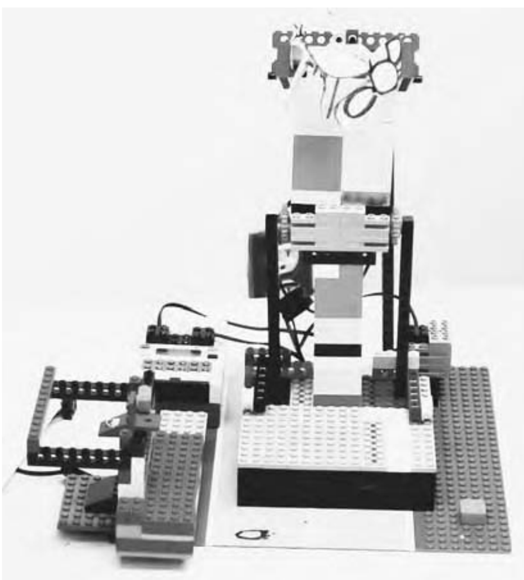



FIGURE 16. Two chairs for Mr. Bear, constructed by first-grade students

look like using the pictures as a source of idea. Pictures also help students get started when they have no idea what to build ("Why don't you try to build something like the blue snow plow on the second page?"). However, students often shun the research ("I have a better idea than any of the ones in the pictures that I am going to build!"). The great thing about the LEGO materials is that they allow for both types of students to build something that will be successful.

FIGURE 17. Transportation inventions

One of the culminating activities is a "Transportation Invention." In this activity, the students are allowed to choose their own problem to work on that solves some sort of transportation issue for people or animals (see Figure 17). Their work posing a problem is scaffolded through drawing and writing ("Who is your invention for? How will it help them?"). They also design their own tests for their invention ("Our tow truck must be able to drive up a hill." or "Our double-decker bus will hold 20 LEGO people."). Last year, we had cars that could transport dogs and cats, double-decker buses for 20 LEGO people, and tow trucks for toy cars.

It's amazing what 6- and 7-year-olds can create and design when they are given time to explore a tool set and build expertise in engineering design. They haven't yet begun to think, "I can't" or "This is too hard." I often see little girls who struggled at the beginning of LEGO Engineering design amazing and imaginative inventions that function perfectly well. The future challenge is to keep the students engaged in these types of activities each year so they don't forget how great they are at engineering. We hope that even this brief introduction to the engineering design process gives students tools to think about how to create their own solutions to the problems they find in their world.

INTERVIEW *with* TERRY GREEN

Insights from Experience

From Lunar Rovers to Chaos

Sia Haralampus

Terry Green teaches science at the Lincoln Public Schools in Lincoln, Massachusetts, and has been working for over 8 years with robotics in early childhood. She has extensive experience developing curricula to integrate robotics with science education.

Sia Haralampus is an undergraduate student in Child Development at Tufts University in the teacher licensure program for Preschool to Grade 2. She is currently completing a final, year-long teaching practicum in a public first-grade classroom and looks forward to using robotics as an integrative tool in early childhood classrooms.

Sia Haralampus (SH): *You have been working for over 10 years with robotics and very young children in your suburban public school in Massachusetts. Can you tell me a little bit about the scope of what you have been doing?*

Terry Green (TG): We've been working with LEGO in this school probably for 10 years. When kids enter first grade we work on how to build sturdy: sturdy walls and sturdy structures so if you drop them they're going to not fall apart. Our goal is to show kids how you put the elements together—the LEGO pieces together—to make a sturdy structure. One of the projects I do in a unit on space is talk about Lunar Rover activity back in the early '60s, and I have the kids build a model of the rover, with one motor. In order for the kids to then get the RCX, they need to show me that if I drop the rover from my knee it's not going to break, and that it is a sturdy structure. For the accomplished builders, I introduce programming by asking, "Can you make this rover go forward for five seconds and stop?" I show them the Pilot Level 1, the simplest level in the RoboLab programming language, which has one motor icon. Sometimes I'll use bubble wrap—so they'll build their rovers and I'll have the moonscape, and they have to then drive their rovers over the bubble wrap—sometimes it involves a design element where they've got to change the wheels in order to accommodate the terrain. If I have a group of first-graders who really get it, who really understand the programming, the second step I do with them is to have them do a two-step program in reverse—that is the Pilot Level 3 program in RoboLab. And I might add the programming of a touch sensor so that if the rover runs into something, like a lunar boulder, the lunar rover will stop the motor. But that is difficult. It requires some abstract thinking for young children to be able to say, "OK I want this touch sensor to stop the car" and then be able to transfer that to a computer program that does it; that is a big leap for kids in first grade that aren't thinking abstractly—they're concrete kinds of thinkers.

In first grade I find it works best if I have helpers with me, so I use parent volunteers, adult helpers. I try to get one or two in a group of about 20 students so that I can differentiate the instruction. I can then help the children who are ready to get on to the computer programming earlier, while the other adults in the class can help the rest build a sturdy structure.

SH: *In my observations of your class, I saw you using paper cutouts for programming the robots.*

TG: The paper program is a way for the kids to think about the steps involved in programming the robot before they get to the computer. First they need to identify the activity they want the project rover to do. Then they have a response sheet I give them to cut and paste paper icons—similar to the ones they have in RoboLab. The kids have to make this program first before I let them use RoboLab in the computer. I have them use two motors, and there is a time element; they have to make the rover go forward and stop at a rock and pick up passengers. Then I give them RoboLab in the computer to test out the time element. Children sometimes like to add other elements to their program as well, such as turning things or noisemakers. I always say to my students, "You should be complimented if someone borrows your ideas," but I always ask the idea-borrowers to change them a little bit to make them their own. In any particular class, and this is certainly true for first- and second-graders, I might have five different levels of activity going on at one time, and it's messy and noisy but quite exciting. To help out with this situation I use student experts, so, for example, if I have somebody who is a little bit more advanced or has tried successfully a new element in the programming or the building aspect, then he or she is the expert on that. Their responsibility is to help other children who are coming across similar problems.

SH: *I noticed a man in the classroom . . .*

TG: He is a retired engineer, part of a volunteering organization that is interested in coming into the classrooms. He's been here about 5 years now. He is really important because he helps a lot. For example, when you came to observe, he was working with a child who had missed the last class and therefore she didn't know what she needed to about gears. He worked with her to get her up to speed. What's really great about him is that my physics is rusty—it's been a while since I've taken any force and motion courses—and he's really good at keeping me on track.

SH: *What were some of your early expectations for children's learning with robotics?*

TG: When I first started I would not have expected kids to be using the program until probably fourth grade. So, I have to admit, I was a little reluctant to bring that in, because at that point in my understanding—I didn't understand it enough to be able to see the potential with young kids. But I am finding that kids intuitively understand computers and how they work, having grown up with that. And so getting on the computer is pretty natural for them. And it's a matter of putting the pieces in place so that when they are on the computer they are really doing the work needed to be productive. To be honest, at the beginning it was quite chaotic, and as teachers, you don't really want chaos in the classroom because it appears that learning isn't going on if the classroom is so chaotic. And for me, I learned that it's okay to have a chaotic classroom because it doesn't mean that learning isn't going on, it just means learning is going on differently.

Management is also an issue—material management and classroom management. I like groups of two, and I typically do boy groups and girl groups. I just like the way they work together. The thing is you'll have 10 projects that are in different stages of completion that need to be saved. You have to have insight about management issues and how to deal with all that "stuff"; so when the kids come in next week they can pick up from where they are. You have to have checks in place, so that when the kids come in they can remember where they were to make that time valuable for them. It took me a couple of years to figure all that out. I had projects all over the room at one point, and I'll have younger kids come in and of course they want to touch them. It's about management, really, managing your materials and figuring out the best way to store those.

SH: *Based on your early expectations, how have your approaches changed over the years? How have you changed the way you bring these elements into the classroom?*

TG: I think kids need time to explore the materials because young children are naturally curious. It is important to have materials available for them to explore, and then slowly introduce things they are ready for, and slowly introduce pieces that can expand what they already have. And they need a lot of time. In the beginning it worried me—"Oh it looks like they're just playing"—whereas play is, well you can call it play, but I call it investigating. They're exploring. Exploring and investigating have an element in it that is more than just play, it's learning about something and being able to communicate what they have learned. I ask children to draw pictures of what they're thinking or what they've found out. And I have them write a little bit about it, especially in second grade. For example, today's class was really about exploring gears and noticing that some are fast and some are slow, depending on how you mesh them. I let them play with the gears because that is when they are going to remember, not if I tell them that gearing up is when the follower does this or that. We've been doing hands-on learning since the '70s . . . but this is experiential learning where you're giving materials to kids, in a controlled place, where you have clear expectations—you know when we're done. I know that I want children to know *this* about the topic. So I've got clear expectations and before the kids leave for the day I can go back to that to make sure that the expectations have been met.

SH: *What sort of suggestions can you make for teachers thinking about implementing a robotics curriculum with young children?*

TG: The hardest thing about using this kind of robotics in the classroom is being comfortable with not knowing the answer. We might have our expectations, but the answer we are expecting might not be the one the kids come to! The first few years were very hard for me because I didn't know what to expect. I had never built these kinds of structures; in fact I had never used LEGOs when I was a young child at all. But I learned that within a classroom community you're always going to have a handful of kids that intuitively have their own answers. I think it's important that teachers are learning along with the kids, and that we don't really have all the answers. And that's what engineering really is. We need citizens of the future that are going to use technology to improve our lives. I think these kids are going to do it. I am hoping that when I am in the nursing home, they are coming up with things to make my life better!

Conclusion

FIGURE 18. Building and playing

This book presents an innovative approach for using technology in early childhood. The approach is guided by the constructionist philosophy developed by Seymour Papert, which suggests that the best way to help children learn with computers is by providing them with tools flexible enough that they can create their own computational projects. As shown in this book, robotics is one such project. Not only can children design, build, and program their own interactive artifacts while having fun, but they can also learn how to work in groups and develop socioemotional skills. In the process, they encounter powerful ideas from the realms of math, science, technology, and engineering. As opposed to limiting children's interactions to a computer screen, robotics invites children to play and to engage in sensory-motor activities, which are fundamental for the healthy development of young children.

Robotics continues a long-standing tradition of learning manipulatives in early childhood. It also opens up a world of possibilities by exposing children early on to traditionally abstract and mechanical concepts such as gears, levers, joints, motors, sensors, programming loops, and variables in a concrete and fun manner, while engaging them in most of the steps involved in the engineering design process. In a world in which technology plays such an important role in our lives, it is wise to expand the range of content and contexts that young children learn about by welcoming explorations of objects made out of both bits and atoms—for example, everyday objects such as automatic doors, motion-sensitive lights, and automatic braking systems in cars, and more complex objects such as space shuttles, robotic surgeons, and bomb-finding robots. However, although all of these objects are interesting to study, a curriculum should not be built around objects, but around ideas themselves.

Given the increasing federal mandate to revisit early childhood programs and make them more academically demanding to meet stepped-up achievement requirements in later schooling, it is a perfect time to rethink what we are teaching our children and how we are teaching it. As this book shows, robotics projects provide an opportunity to focus on a pedagogy that embraces playful learning through the creation of personally meaningful projects while simultaneously enhancing curricula to strengthen the teaching of math, science, technology, and engineering.

One of the obstacles to incorporating robotics into the early childhood classroom is that early childhood educators have had little or no experience with technology or engineering concepts and processes. There is a lack of resources and theoretically accepted guidelines for working with younger children in this area. Thus, many early childhood educators are unaware of the potential of robotics construction kits as appropriate learning manipulatives. This book provides a window into these issues by presenting a theoretical approach, practical guidelines for doing the work, and information on further resources. Most of the projects and examples in this book use LEGO Mindstorms because this is the commercial robotics kit most widely available and supported for educational uses. The pedagogical and developmental theories discussed here go beyond this particular construction kit, however, and apply to any robotic manipulative or technology that allows children to combine bits and atoms to design a personally meaningful project that can exhibit behaviors by responding to inputs.

The core message of this book is that by providing children very early on with powerful tools such as robotics, which are natural digital extensions of traditional learning manipulatives, we can help them develop readiness to become producers, and not only consumers, of technology. Thus, children will develop the skills and ways of thinking needed to solve problems using technology, not only in the classroom but in society at large.

APPENDIX A

Engineering and Technology Standards in the United States

The table on the following pages is a state-by-state summary of standards for education in engineering and technology in the United States as of 2006. At the time of compilation of the data, most states included separate engineering/technology standards within their curricular frameworks. Missouri was the only state with no standards for education in engineering and technology.

Information presented in the table was provided by Yvonne Spicer, National Center for Technological Literacy (NCTL), Boston Museum of Science.

For complete, up-to-date information regarding technology and engineering frameworks, check the NCTL website: http://www.mos.org/nctl/

State	Standards by Subject					Notes on Standards	Standards by Grade Level		
	None	Separate Academic	Sci-Eng Academic	Technol Ed	Voca-tional		Elemen-tary	Middle School	High School
TOTALS:	1	4	23	11	31				
Alaska			✓		✓	Industrial and Engineering Technology. Science, technology, engineering, and math industry-driven set of standards for course and program content. Involves technological design		✓	✓
Alabama					✓	Technology Education framework covers use of technology. Career Technology (Technology Education) covers applications of technology and engineering related concepts		✓	✓
Arkansas					✓	Exploring Industrial Technology. Courses and standards at middle and high school levels. Pre-engineering course sequence		✓	✓
Arizona			✓			Technology Education Standards cover computer literacy K–12. Science Standards Strand 3, Science in Personal and Social Perspectives, has design expectations	✓	✓	✓
California					✓	Engineering and Design Strand in Career and Technical Education. Contains 5 engineering pathways		✓	✓

Colorado			✓		✓	Science frameworks integrate science, technology, and human impact. Some design elements are covered. Most of the standards involve “describe”; however, elementary does have an “invent” standard and high school a “demonstrate” standard	✓	✓	✓
Connecticut			✓	✓		Connecticut Framework K–12 Curricular Goals and Standards—Technology Education. Standards in science include design concepts and problem-solving using engineering processes	✓	✓	✓
Washington, DC			✓			Science Technology and Society in Science Strand			✓
Delaware			✓	✓		Technology Education Standards: 2000. Public K–12 technology education standards. Science Curriculum Framework Standard One: Nature and Application of Science and Technology	✓	✓	✓
Florida				✓	✓	Standardized courses for engineering technology. Science standards are K–12; technology education standards are middle and high school		✓	✓
Georgia				✓		Technology education standards related to courses middle through high school. Assessment requirements for course completion		✓	✓

State	Standards by Subject					Notes on Standards	Standards by Grade Level		
	None	Separate Academic	Sci-Eng Academic	Technol Ed	Voca-tional		Elemen-tary	Middle School	High School
Hawaii			✓	✓		Technological design is integrated into a number of subject matter areas. Science has two technology standards related to society and impact of science/technology. Technology design is part of Career and Technology in K–12. Elementary uses KITS materials	✓	✓	
Iowa					✓	Industrial technology			✓
Idaho			✓	✓	✓	Standards for technology and engineering are in different divisions. Science standards include technology (technology design) and personal/social perspectives. Technology education is under the Division of Professional and Technical Education. Statewide standards are from 2001, grades K–12	✓	✓	✓
Illinois			✓		✓	Illinois Learning Standards are for mathematics, English language arts, and science (with science, technology and society, and technological design sections). Industrial technology state curriculum slated for 2006			

Indiana			✓	✓		Most middle school students in Indiana take a technology and engineering course. The curriculum is designed for 36 weeks. Not all schools offer it, but the majority do. Science K–8 has “understanding science and technology” as Strand 1; has some limited “engineering” applications		✓	✓
Kansas			✓		✓	Technology Education, Science and Technology (which includes design), and Science in Personal and Environmental Perspectives (social impacts of technology), K–12	✓	✓	✓
Kentucky				✓	✓	Curriculum Framework for Technology Education. Science standard mentions use of science in technological design and relations of science and technology to society		✓	✓
Louisiana				✓	✓	Technology Content Standards		✓	✓
Massachusetts		✓			✓	Part of the Science and Engineering/Technology Curriculum Frameworks. Massachusetts also has a Vocational Technical Education Curriculum Framework for Engineering Technology	✓	✓	✓
Maryland				✓		Technology education standards: “Technology education is a state graduation requirement”		✓	✓

State	Standards by Subject					Notes on Standards	Standards by Grade Level		
	None	Separate Academic	Sci-Eng Academic	Technol Ed	Voca-tional		Elemen-tary	Middle School	High School
Maine			✓			1997 standards for science and technology	✓	✓	✓
Michigan					✓	Education technology standards centered around using technology to problem-solve, etc. Science: students must be aware of how technology affects society	✓	✓	✓
Minnesota			✓		✓	Technology Education Teachers Association is supporting implementation of the national standards			
Missouri	✓					Standards for core curriculum only. Missouri is the only state with no standards for education in engineering and technology			
Mississippi				✓	✓	Frameworks for two courses at the secondary level: Technology Discovery and Technology Applications			✓
Montana			✓			Science Content Standard 5 includes technology. State has "Technology" standards that relate to the use of computers	✓	✓	✓
North Carolina				✓		Technology education courses and standards		✓	✓

North Dakota			✓	✓	✓	Science standard makes distinction between science and technology. Includes "Technological Design"	✓	✓	✓
Nebraska			✓			Covers some engineering and technical literacy concepts. A separate section on technology and society covers design and application areas	✓	✓	✓
New Hampshire			✓	✓	✓	Frameworks for Science Literacy, K–12, integrate design technology, tools, and social issues into each science discipline	✓	✓	✓
New Jersey		✓				Curriculum frameworks for technological literacy, K–12, include both computer/career and engineering/technology activities	✓	✓	✓
New Mexico					✓		✓	✓	✓
Nevada			✓		✓	Under Science standards, students get only an "understanding"; they do not actually build, design, or test technology. Computer and Technology standards integrate activities for students to design and test technology	✓	✓	✓
New York			✓		✓	Technology education covered under the Mathematics, Science, and Technology Learning Standards	✓	✓	✓

State	Standards by Subject					Notes on Standards	Standards by Grade Level		
	None	Separate Academic	Sci-Eng Academic	Technol Ed	Voca-tional		Elemen-tary	Middle School	High School
Ohio		✓		✓	✓	Technology Academic Standards. Included is a section on technical literacy described as skills needed to live in a technical society and understanding of the engineering process	✓	✓	✓
Oklahoma				✓		Technology education focused on interdisciplinary application to design and technical projects. Curriculum standards for grades 6–10 and 11–12		✓	✓
Oregon					✓				✓
Pennsylvania			✓			Academic Standards for Science and Technology (2002), K–12	✓	✓	✓
Rhode Island			✓			Grade Span Expectations for Engineering Technology are segmented into grade spans of K–4, 5–8, and 9–12	✓	✓	✓
South Carolina				✓	✓			✓	✓
South Dakota					✓	Technology Education Content Standards. Science standard also includes technological design at the high school level	✓	✓	✓

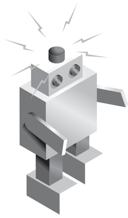
Tennessee					✓	Engineering Technology Education. Five courses	✓	✓	✓
Texas			✓	✓	✓	Technology Education, Industrial Education		✓	✓
Utah				✓		Engineering standard is under Technology Education		✓	✓
Virginia					✓	Standardized courses with specific task lists for each course. Courses in technology education include many engineering options	✓	✓	✓
Vermont					✓	Engineering technology is a content area under Career and Technical Education. It focuses on the high school level and has specific competencies for each engineering course in the sequence			✓
Washington			✓		✓	Science standards with some embedded technology/design concepts cover all grades	✓	✓	✓
Wisconsin		✓				Standards for Technology Education are integrated for all elementary grades	✓	✓	✓
West Virginia				✓		Content standards under Career and Technical Education. Technology education courses		✓	✓
Wyoming					✓		✓	✓	✓

APPENDIX B

Sample Curriculum Starter

The next page shows an example of how to develop a curricular web that integrates robotics with other disciplines. It was developed by Marina Bers and Debbie LeeKennan as part of an Early Childhood Teachers Summer Institute conducted in August 2006 at Tufts University.

During the institute educators learned how new robotics technologies could be used with young children and integrated with the math, science, technology, and engineering (MSTE) curriculum. They received (1) one free LEGO Mindstorms robotics kit after completion of the institute, (2) access to our free lending library of robotics kits to use in the classroom, (3) the opportunity to conduct guided observations of young children learning and using these materials in our Early Robotics Summer Camp, (4) a package with already-developed activities that make use of this technology with this age group, and (5) 18 PDP points. By using a curricular web, educators developed and implemented their own robotics curriculum.



Curriculum Starter

Robotics

Literacy
reading
writing
literature extensions
story telling

Math
graphing
measurement
block building
number sense
geometry
patterns

Social Studies
mapping
geography
history
family

Science
cause and effect
life cycle
physical world
earth and space

Technology/ Engineering
design process
simple machines
mechanics
programming

Arts
music
dramatic arts
dance/movement
visual arts
collage/sculpture

Curriculum Questions:

How can robotics facilitate learning in the different curriculum areas?

How can robotics integrate the different content areas?

What are objectives (What will students learn?)

How do you assess what students learn?

How do you adapt curriculum to meet the needs of a wide range of learners?

How does this connect to the Massachusetts Curriculum Frameworks?

APPENDIX C

Sample Design Journal

The design journal shown on the following pages was developed by Kevin Staszowski for an early childhood robotics summer camp conducted at Tufts University in August 2006. The theme of the camp was the circus as a starting point for children to build robotic projects.

Children were exposed to a curriculum that taught them the basics of building and programming with robotics by inviting them to create a flying trapeze, a music box, and men traveling across a tightrope, who, when hit by a spotlight (a flashlight), jumped down into a net. As a grand finale, during the last two days of the workshop, children created their own open-ended projects, such as a machine that delivers candy or a monkey that can jump up and down. Families and friends were invited to the open house to see the projects. Children used this design journal to write down their ideas for projects and to reflect on their learning experience. At the end of the workshop the journal was taken home, where it served as a way for the children to share their experience with their parents.

For a free, printable version of this Appendix, visit www.teacherscollegepress.com

Circus Program

My name is ______________________________

My partner's name is ________________________

Draw what you think you and your partner are going to build:

What did you draw? ______________________________

____

____

What is its name? ______________________________

____

What are three things you want your project to do?

1. ____

____

2. ____

____

3. ____

____

I will build ______________________________

____

____

My partner will build ______________________________

____

____

BUILDING NOTES

This is a picture of what my partner and I worked on today

We finished working on ______________________

____

____

We still need to work on ______________________

____

____

BUILDING NOTES

The easiest thing I did today was ______________________________

____

____

____

____

The hardest thing I did today was ______________

____

____

____

____

____

What is an idea you got from another team or an adult? ______________________________

____

____

____

This is a picture of my partner and me with our final project

When I run my project, it ________________________

____

____

____

My favorite part of the project was

When I worked on my project, I learned how to

My favorite part of working with my partner was

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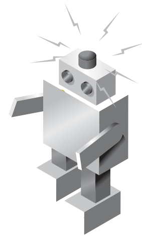

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