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Teachers as Designers: Integrating Robotics in Early Childhood Education

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This article presents a constructionist approach to introducing technology, in particular robotics, in the early childhood classroom. The authors demonstrate how this approach is well suited, since the four basic tenets of constructionism have a long-standing tradition in early childhood education: (a) learning by designing meaningful projects to share in the community, (b) using concrete objects to build and explore the world, (c) the identification of powerful ideas that are both personally and epistemologically significant, and (d) the importance of self-reflection as part of the learning process. This article introduces a methodology for teaching preservice teachers to integrate technology in the classroom. It also describes four different experiences in which preservice teachers designed and integrated robotic projects done with LEGO Mindstorms and *ROBOLAB* to engage their young students in exploring and learning new concepts and ways of thinking.

Early childhood education (Pre-K to 2) has long recognized and agreed upon the benefits of using constructivist methodologies to help young children learn by doing, by manipulating materials, by engaging in active enquiry, and by creating playful experiences. In the last decade, there has been an increase in the demand for, and the controversies over, introducing computers in early childhood education settings. However, the question is not whether computers will come to the early childhood classroom or not. They are already there. Today almost every preschool has a computer, with the ratio of computers to students changing from 1:125 in 1984 to 1:22 in 1990 to 1:10 in 1997 (Clements, 1999).

The question instead, is how to integrate computers into the constructivist practice and philosophy already widespread in early childhood education. The use of robotics supports this integration by engaging children and teachers in the active design of meaningful projects. These projects combine manipulative materials they are familiar with and other new ones. For example, *robotic construction kits such as LEGO Mindstorms, offer a new kind of manipulative for young children to explore and play with new concepts and ways of thinking*. However, very few teachers have the experience and skills to conduct this kind of activity. In the best cases, they know how to use some computer applications, but haven't developed true technological fluency. This term refers to the ability to use and apply technology in a fluent way, effortlessly and smoothly, as one does with language. For example, 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, 1995). As with learning a second language, fluency takes time to achieve and requires hard work and motivation.

Many wonderful teachers who follow a constructivist pedagogy, when faced with the challenge of using computers in the classroom, revert to instructionist ways of teaching and learning. They lack the needed training and expertise. Most early childhood education programs do not prepare teachers in the area of technology nor do they offer a vision in which teachers see themselves as designers of technologically rich curricula, and not merely consumers.

This article presents a constructionist approach to introducing technology, in particular robotics, in the early childhood classroom. The authors demonstrate how this approach is well suited since the basic tenets of constructionism are already present in early education. The article introduces a methodology for teaching future teachers to integrate technology in the classroom by describing and analyzing the experience of a course at Tufts University's Department of Child Development on designing technologically rich curricula. In this context, preservice teachers worked with robotic projects in the early childhood classroom. The article presents four learning stories from this experience.

CONSTRUCTIONISM: LEARNING BY DESIGNING

The work described in this article is based on the constructionist philosophy of education, which asserts that people learn better when they are engaged in designing and building their own personally meaningful artifacts and sharing them with others in a community (Papert, 1980). By constructing an external object to reflect upon, people also construct internal knowledge. Constructionism has its roots on Piaget's constructivism. However, while 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. Computational environments are powerful tools to support new ways of thinking and learning by engaging users in the design of meaningful projects (Resnick, Bruckman, & Martin, 1996).

Constructionism is situated in an intellectual trajectory that started in the 60's with the Logo group directed by Seymour Papert, based first at the Artificial Intelligence laboratory at MIT and later at the MIT Media Laboratory. Although many different research agendas and goals permeated the group, there was a shared vision with at least four pillars. *First, the belief in the constructionist approach to education*. This implies the need of setting up (computational) environments to help children learn by doing, by active inquiry, and by playing with the (computational) materials around them to design and make meaningful projects to share with a community. *Second, the importance of objects for supporting the development of concrete ways of thinking and learning about abstract phenomena.* It is in this context that the computer, as a powerful tool to design, create, and manipulate objects both in the real and the virtual world, acquired a salient role in the vision of the Logo group. *Third, the notion that powerful ideas empower the individual.* They 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). *Fourth, the premium of self-reflection.* The best learning experiences happen when people are encouraged to explore their own thinking process and their intellectual and emotional relationship to knowledge, as well as the personal history that affects the learning experience.

CONSTRUCTIONISM IN EARLY CHILDHOOD EDUCATION

Early childhood education has a long-standing tradition of engaging young children in the creation of their own personally meaningful projects. As the authors will demonstrate in this article, the four tenets of constructionism previously described are, and have been, present in early childhood: (a) learning by designing meaningful projects and sharing them in a community, (b) manipulative objects to help concrete thinking about abstract phenomena, (c) powerful ideas from different realms of knowledge, and (d) self-reflective practice. Constructionism can be a helpful guiding philosophy for thinking about how to introduce computers in the early classroom. It shares a theoretical basis with practices that have already been implemented successfully.

Learning by Designing

Developmentally appropriate practice in early childhood education pays attention to the individual interests of the child as well as the community in which learning happens (Bredekamp & Copple, 1997). In this context, teachers are asked to design a learning environment to support children in their explorations, to scaffold learning, and to provide interesting materials for children to manipulate in order to make concrete projects to share with others in the community (Bers & Urrea, 2000). These ideas are the core of constructionism, which has focused on designing computational learning environments that support all of the tenets. For example, to support children's explorations, computational environments must provide tools for learners to become designers of their own projects. As Mitchel Resnick pointed out, children's interactions with technology should be more like finger painting than watching television (Resnick, 2000).

In elementary and high school education, there sometimes exists the tension between an i*nstructionist* model of teaching, in which the teacher's role is to instruct students by transferring or providing information, and a *constructionist* model. However, in early childhood education there is general agreement about the efficacy of "learning by doing" and engaging in "project-based learning." Computers can complement these already established practices and even extend both children's and teacher's experiences to "learning by designing" (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998). This approach engages students in learning by applying concepts, skills, and strategies to solve real-world problems that are relevant and personally meaningful. In the process, learners engage in problem-solving, decision-making, and collaboration (Rogers, Kearns, Rogers, Barsosky, & Portsmore, 2001).

Objects to Think With

The potential of using objects to think and learn with has a long-standing tradition in early childhood education. During the 1800s Montessori and Fröbel 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 of the early childhood settings are populated with Cuisenaire Rods, Pattern Blocks, and other manipulatives carefully designed to help children build and experiment. More recently, but in the same spirit, “digital manipulatives” (such as programmable building bricks and communicating beads) have been created to expand the range of concepts that children can explore. 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, 1998; Resnick, Berg, & Eisenberg, 2000).

It is within this tradition that robotics presents a wonderful opportunity to introduce children to the world of technology. Not only can children design and build interactive artifacts using materials from the world of engineering, such as gears, motors, and sensors, but they are also encouraged to integrate art materials and everyday objects to make their projects aesthetically pleasant. In the next section the LEGO Mindstorms robotic construction kit that was used in the experiences described in this article will be explained.

Powerful Ideas

Over the years, a growing community of constructionist researchers and educators have used the term powerful ideas to refer to a set of intellectual tools worth learning, including both mental processes and domain content (Papert, 1980). When skillfully used, powerful ideas are empowering because they afford new ways of thinking, not only about a particular domain, but also about thinking itself. Powerful ideas are powerful in their use, powerful in their connections to other domains of knowledge and personal interests, and powerful in their roots by being successful in the historical marketplace of ideas (Papert, 2000). The notion of powerful ideas has some resemblance to the concept of "wonderful ideas" as the essence of intellectual development proposed by Eleonor Duckworth (1972). Wonderful ideas are personal insights or revelations that provide a basis for thinking about new things, but 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 the stepping into a new stage. Wonderful ideas are results of an individual's previous knowledge combined with intellectual alertness to ask new questions and play with materials in new ways.

Although powerful and wonderful ideas have many things in common, particularly, such as the fact that they are key aspects of learning, they stress slightly different dimensions. 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 very powerful, from an epistemological perspective, and children should be given the chance to explore them.

The constructionist notion of powerful ideas, and the emphasis on establishing personal connections with children's own intuitions and interests, are consistent with what the field of early childhood education has called emergent curriculum (Rinaldi, 1995) or integrated curriculum. For example, NAYEC 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 that are applied across disciplines, that are generative across disciplines (i.e., that support the development of new ideas and concepts) and that emerge from and connect to children's personal interests (Bredekamp & Rosegrant, 1995).

Both constructionism and developmentally appropriate practice are based on Piaget's model of how people learn. Therefore, there is shared agreement about helping children make their own ideas by active experimentation and interaction with the world around them. In the process, powerful ideas emerge and are encouraged by skillful teachers.

Self-reflection

Self-reflective practice has acquired a more predominate role in early childhood education with the emphasis put in documentation by the Reggio Emilia approach (Rinaldi, Gardner, & Seidel, 2001). Documentation 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).

The use of documentation, by both students and teachers, as a way to engage in self-reflection is consistent with the emphasis put on using design journals, pin ups, and open houses in constructionist experiences. Documentation is a wonderful vehicle for making self-reflection concrete and being able to share its products with others. As is seen later in this article, the documentation done by the student-teachers who participated in the projects described in this article, served as a basis for sharing with others, in the form of an open house, their own learning experiences.

A technology for designers: Hardware and software. Although many different technologies lend themselves to engage learners in a design process, robotic construction kits are particularly useful with young children because, by engaging them in the construction of physical artifacts, they foster the development of motor skills, along with technological fluency. The robotic construction kit that was used in the experiences reported in this article was LEGO Mindstorms.

This technology consists of both hardware and software. The hardware is composed of the LEGO Mindstorms RCX, a tiny computer embedded in a LEGO brick (Figure 1). This autonomous microcomputer can be programmed to take data from the environment through its sensors, process information, and power motors and light sources to turn on and off. An infrared transmitter is used for sending programs from the computer to the Mindstorms RCX. The Mindstorms RCX has been the result of the collaboration between LEGO and researchers at the MIT Media Lab.

Figure 1. The RCX programmable brick with wheels, motors, and sensors

The software consisted of *ROBOLAB*, a graphical programming environment with tiered levels of programming (Portsmore, 1999). It allows users to drag and drop graphical blocks of code that represent commands such as left and right turns, reverse direction, motor speed, motor power, and so on. Users can drag the icons together into a stack, in a similar way than assembling physical LEGO bricks, and arrange them in logical order to produce new behaviors for a robotic construction (Figure 2). The *ROBOLAB* software is a result of a three-way partnership between Tufts' Center for Engineering Educational Outreach, LEGO DACTA, and National Instruments.

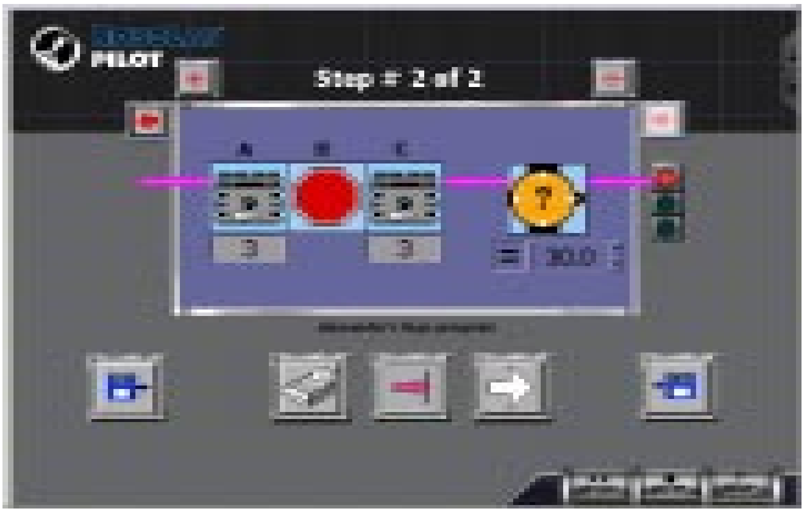

Figure 2. The *ROBOLAB* programming environment

DESCRIPTION OF THE COURSE METHODOLOGY

The experiences with robotics presented in this article resulted from engaging student-teachers in a "learning by design" experience in a graduate level course aimed at teaching them both the technical aspects of working with technology and robotics and the philosophical aspects of a constructionist learning environment. Preservice teachers became designers of their own technologically-rich curriculum by using *ROBOLAB* and LEGO Mindstorms. They were also in charge of documenting their experiences online throughout the project. This culminated in an open house where the process and findings were presented to other members of the community, such as faculty, teachers, parents, and children. The course was conceived based on the four tenets of constructionism: Learning by design, objects to learn with, powerful ideas, and the premium of self-reflection.

Students engaged in all the different facets involved in “learning by design” experiences: They developed an artifact, tested, evaluated, refined, and improved it in an iterative process based on criteria that they had established in advance. In this experience, failure was considered as informative, often more so, than success. This process engaged students in reflection and collaboration in three different ways: (a) by talking about their design process and sharing drawings, sketches, and models to generate feedback, (b) by documenting each step of the project in a medium that lends itself to collaborative efforts such as the World Wide Web (WWW or Web), and (c) by presenting the final robotic artifacts and pilot projects with them in an open-house for the public.

The premise of the course was that if preservice teachers need to be educated to integrate technology into the curriculum, to develop technological fluency, and to see themselves as agents of change in the way computers are introduced in early childhood programs in a constructionist way, they first need to experience it themselves. Teaching them computer skills or theoretical classes on philosophical approaches to use computers in the classroom is not enough. They need to engage in a learning by design experience.

Of course, when these teachers go out to the early childhood classroom, they will find that not everything they have learned is developmentally appropriate for their young students. However, teachers need to be prepared to teach as if their students could engage in the whole design process, and later identify how they will adapt the design activity and technology according to the different ages and needs of the children.

In the following section, some examples of how the design process was adapted by preservice teachers to be used in the classroom with children as young as three years old are presented.

LEARNING STORIES

In this section four learning stories in which student-teachers used robotics in the early childhood classroom and integrated it with other areas of the curriculum are presented. In the first story, *ROBOLAB* and Mindstorms were used with three-year-olds to explore the concept of change though metamorphosis. In the second story, the same technology was used to explore the concept of balance with four-year-olds. The third story is about how robotics was used to understand the notion of life cycle. The final story presents an experience in which first and second graders became involved in the design, building, and programming of a robotic project (i.e., a dinosaur to scare away the squirrels of their tulip garden). The stories progress not only by age of the participants but also by the degree in which children themselves were involved in the design process. However, in all of the stories, student-teachers played the role of designers by designing not only the technology to be used but also the way it was integrated into the curriculum.

Understanding Change through Metamorphosis

The learning story described in this section shows how a group of 12 three-year-old children explored the concept of change through an understanding of metamorphosis. Over a three-month period 12 children took part in an in-depth study of metamorphosis that culminated in a project using robotics with the LEGO Mindstorms kit.

Prior to this project all 12 children were unable to identify the phases of metamorphosis. For example, while reading the *Hungry Caterpillar* storybook (Carle, 1969) and playing with a clothesline that depicted the stages of the story for the children to look and play with, one boy told to his friend: “Look there are two animals here! A caterpillar and a butterfly!” (Figure 3). This little boy did not understand the concept that the insects were one and the same. By the end of the project, however, the majority of the children understood that although the exterior of the caterpillar changed throughout the phases, it was still the same insect. In fact, eight of the 12 children were capable of labeling the entire sequence.

Figure 3. Children playing with clothesline representing stages of metamorphosis

Metamorphosis is defined by Webster's Dictionary as a profound change from one stage to the next in the life history of an organism, a complete change of form, structure, or substance. The notion of metamorphosis is a very powerful idea, not only because it brings new ways of thinking about change and it is pervasiveness outside of the classroom, but also because it connects with children's personal struggles to understand that regardless of how we may change in the inside (through personal experience, growth, emotional change, etc.) we always remain ourselves.

The activity. To start exploring the concept of metamorphosis, the student-teacher read to the three-years old Eric Carle's *The Hungry Caterpillar* and engaged them in playing with a colorful clothesline depicting the caterpillar's journey through various food items, becoming first a cocoon and finally a butterfly. After introducing them to the concept of metamorphosis and allowing them time to play with the clothesline, the student-teacher showed to the children three puppets: a caterpillar, a cocoon, and a butterfly. Then she introduced the caterpillars' heart, which she built and programmed with the LEGO Mindstorms programmable brick.

Children were asked to design the three environments that the caterpillar would move through its life cycle: the leaf environment, the branch environment, and the cloud environment. The environments were laid in order on the floor and children took turns placing the corresponding puppets on the Lego heart as it moved through the environments (Figure 4). The children had a great time watching the heart move across their created environment and helping the metamorphosis happen right before their eyes.

Figure 4. A three-year old mounting a cocoon puppet on a robotic heart

To assess children's learning about metamorphosis, the student-teacher had them participate in a posttest. She also used extensive documentation, note taking, digital photography, and video recording on the children's reactions, discussions, and conversations, as well as the children's interaction with the technology.

Overall this project was successful. Not only did the children have a wonderful time participating, they also learned about a very complicated topic that traditionally was only approached with older children. This happened for many reasons. First and foremost the basis of this project was a powerful idea formed by the children themselves. For this reason there was an authentic interest in the project. Secondly, this project used a new technology that "enhanced the creative, aesthetic, and personal dimension of students' scientific inquiries" (Martin, Mikhak, Resnick, Silverman, & Berg, 2000; Resnick et al., 2000). The children felt a strong personal motivation in the project because they created the environments that the "heart" would be traveling through. In the end, not only did the majority of the children understand the concept of metamorphosis but also they were able to go into detail about the process. "The caterpillar is in the cocoon for about two weeks," one girl explained.

In this learning story children used technology in its most basic form. Although they did design the environment for the caterpillar, they did not experience the technical building or programming. These children were only three years old. The student-teacher struggled hard to find ways of integrating the technology into the curriculum that was already happening in the classroom, without disrupting the constructivist model of learning that involves the use of concrete manipulatives. When children are so young, one of the most dangerous traps of using technology in the classroom is to turn the computer into a TV set for children to sit and watch CD-ROMS or use video games that do not invite creativity. As is shown in this project, children used technology in a very different way.

Exploring Balance

Young children explore the concept of balance through their everyday work and play. A curriculum project was designed to help four-year-old preschool children explore their growing understanding of balance. As part of the project children were given the opportunity to work with a crane that was built from a LEGO Mindstorms Kit and programmed with *ROBOLAB*.

By using the crane as a tool for exploring balance, the children experienced a new way of playing with this powerful idea, and were provided with an occasion to talk about and share their current understandings of balance.

Most children of this age struggle with the concept of balance. Balance is embedded in everything they do from simply walking to building complex Domino mazes. Although young children aren't aware of exactly what they are grappling with, they do know that there is a reason why they can't build their Unifix Cube towers to the ceiling and that they have difficulty jumping on the shaky bridge without holding on to the railing. To explore these frustrations, children use trial and error. They try a new strategy of adding cubes to the tower or move their body in a slightly different motion. With each attempt they move closer to understanding what creates balance.

According to the Webster Dictionary, to balance is to, " bring to a state of position of equilibrium." In life, we are continuously attempting to reach this physical state, either with our own bodies or with tangible objects. We are urged to practice and perfect this ability, as it seems essential to so much of what we do. Balance is a "powerful idea" for all people and especially for young children as they begin to understand their physical world, their body motions and how to best manipulate objects for projects like structure building. Since objects are balanced by having their weight equally distributed, it is important for children to understand the effects of adding and subtracting weights from something that is balancing or attempting to be balance. For example, in the science curriculum section of the Massachusetts frameworks it is suggested that students in preK-2 should be able to "recognize that under some conditions, objects can be balanced." To help children understand the idea of balance, the student-teacher used the Lego Mindstorms kit to build a crane that would transport magnets from one side of a wall to another.

The activity. The activity took place during choice periods in a four-year-old classroom. First, the student-teacher read a book to the children, which tells the story of a crane. She then invited the children to experiment with the crane in a collaborative way. The challenge was for each child to pick up metal pieces with the magnet on the crane and transport it to the other side of the wall by controlling the crane with a touch sensor. To complete the task the child had to add and take away tokens from either side of the lever (Figure 5).

Figure 5. Children suggesting to each other where weight should be added

First the child needed to figure out a way to make the magnet side of the crane more weighted so it could pick up magnets off the table. Next the child had to balance the crane for it to rotate over a short wall without hitting it. Once on the other side, the child needed again to redistribute weight for the magnet to touch the table or floor surface. The child was encouraged to go back and forth delivering magnets for as long as he or she wanted to.

As a result of their experimentation with the crane and the magnets, the discussion that occurred among the children during this activity was very rich. For example, children were talking about making the baskets equal for it to balance. "Three in this side and three in that side." They began by simply adding pieces and then progressed to taking away pieces, as well. When the student-teacher asked the children what it meant to balance the crane, one child answered, " You have to make it equal."

In building the crane the student-teacher was also personally challenged to re-visit the concept of balance. During the design process she had a hard time getting the lever to balance. It was very frustrating for her but with some trial and error she figured it out. At one point she stated, "I learned so much about balance just by making the crane!"

The children who experienced this activity thoroughly enjoyed it. In particular, they liked being in control of the crane and its movement. For many children the activity was not appropriate. The scale of the LEGOs was too small, and thus required a great deal of fine motor ability, which many four-year-olds have not yet mastered. Due to their young age, it wasn't developmentally-appropriate to engage or expect children to participate in the whole design process of the crane, as their student-teacher did. However, the crane was a fun and different way for children to explore the concept of balance by being in control of what looked like a sophisticated new type of technology and by engaging in the scientific process of making predictions.

The Life Cycle in Motion

The concept of life cycle—how humans, animals, and plants live, grow, and die—is very appealing to kindergarten age children who are fascinated by living things. Most schools have live animals and plants for children to observe and take care of. For example, the kindergarten that this learning story presents provided many life cycle experiences: children had a slug in their classroom and wondered how it had laid eggs, they watched a caterpillar change into a butterfly, and they had started planting bulbs. The notion of life cycle is powerful not only because it helps children think in new ways about nature, but also because it challenges them to think about their own life stages. The Massachusetts frameworks specifically refer to the life cycle as one of the areas that needs to be covered in the science curriculum for pre-K to second grade.

There are many ways to engage students in learning about the life cycle. Many teachers engage students in observing butterflies or frogs, building a habitat for a live animal and planting bulbs. How can technology be integrated into this kind of activity? What can robotics add to this hands-on experience with nature?

The activity. In the experience described in this case study, the student-teacher engaged children in all of the previous activities. Tadpoles were brought into the classroom. The student-teacher used the opportunity to initiate conversation about the concept of the life cycle and change by engaging them in scientific enquiry and predictions about what would happen next. The children's answers showed that they did not fully understand the concept of the tadpole's life cycle. For this reason, the student-teacher developed a rich curriculum to explore the life cycle and how tadpoles change into frogs.

For this project each child documented in a journal, the changes they observed at regular intervals in the animal, they heard and discussed stories such as *Fish is Fish* by Lionni, that deal with the life cycle of a tadpole. They were also introduced to other familiar things with highly visible life cycles such as butterflies and trees. One part of the curriculum involved the design of a robotic contraption using the LEGO Mindstorms kit. The student-teacher designed and built a motorized wheel to explore with the children the idea that life is cyclical. The contraption consisted of a spinning wheel and a touch sensor. Attached to the wheel with Velcro were five pictures of the different stages of tadpole development. The teacher programmed the wheel to spin slowly with each picture passing a window where it could be clearly seen.

Children had to remove each picture and place it on a paper strip in developmental order. The wheel was programmed to spin until a touch sensor was activated to stop the rotation, at this time the child could remove the desired piece and then begin the process again. This was repeated with pictures of other animals and plants that they were learning about. The children's observational drawings were also used on the wheel.

The robotic contraption was used at the beginning of the unit to gauge what children knew about the life cycle and at the end of the unit to see if they could generalize what they learned about tadpoles to other animals. Children were not engaged in either the engineering design of the wheel, or the programming of its movement. However, they were in charge of controlling the contraption and deciding the chronological order of the stages of a tadpoles' life cycle by operating the wheel and its motion (Figure 6). They were very motivated to engage in the activity because of their interest in learning about the gears and the functioning of the technology.

Figure 6. A girl controlling the robotic wheel with her own drawings of the life cycle

Since the robotic wheel was big and circular it allowed children to sit around it and work in a collaborative way. At first, children showed an understanding of how the tadpoles develop into frogs, but they did not appear to grasp the idea of the cycle—that these stages happen not just once, but continue to repeat for each generation. The spinning wheel became an important piece for helping children understand this concept. By seeing the cycle repeat itself, the children were able to gain a better grasp of how the life cycle works. The motion of the wheel was crucial to get across the idea of the cycle of life.

In this learning story, the full potential of engaging children in a design experience was not explored. This was due to several factors: the young age of the children, the lack of time in the classroom, the limitations of the technology, and the lack of prior technological fluency of the student-teacher, who was learning how to design, make, and program the robotic artifact at the same time that he was using it in the classroom. Had he been more experienced with the technology, he would have been able to engage children in a similar kind of design experience than the one he went through.

Design Process

Young children are natural engineers—they build forts, towers of blocks, sandcastles, and take apart their toys to see what is inside. Similarly, at this early age, children are to some degree familiar with LEGOs. By the time kindergarten begins nearly every American child has played with LEGOs, or at least knows what they are. Using this familiar medium helped to develop the powerful idea of involving children in all stages of the design process.

Choosing a topic that is important to the children to explore through the design process furthers the personal connections, and thus children's desire and motivation to learn. The first and second grade students that participated in this project were learning about tulips. They had planted a tulip garden, and were concerned that squirrels would dig up their tulip bulbs. The student-teacher chose to explore this problem with the students, and asked them to find a way to protect the tulip bulbs from the squirrels using LEGOs and *ROBOLAB*.

The head teacher assigned a specific expert role to each child based on strength and learning style: builder, designer, programmer, documenter-photographer, documenter-recorder. Children explored the design process by using the following steps to solve a problem: (a) identify the problem, (b) brainstorm solutions to the problem, (c) choose one idea to develop, (d) design the solution, (e) build the solution using LEGOs, (f) program the creation using *ROBOLAB*, (g) document the process, and (h) present the project to a wider audience.

Becoming familiar with the engineering design process is a large part of the Massachusetts frameworks for Science and Engineering/Technology. In the process they learned about physics, engineering, and technology, and developed teamwork techniques and communication skills through their own exploration, inquiries, and experimentation with different ideas. The project presented in this learning story is an example of a constructionist experience of integrated and emergent curriculum as described earlier in the article.

The activity. The development and maturation of the designers understanding of the technology being used was apparent in the progression of their designs. The first design, which was created before the children had a chance to explore and build with the LEGO pieces, was more or less a drawing of a dinosaur that breathed fire. There was no reference to the materials that the dinosaur was to be built out of, or the construction of the dinosaur. The second design, which was created after the first day of building, included more references to the technology being used. The RCX appeared in the design. The tail was on the ground with wheels attached, rather than sticking up in the air, LEGO pieces were also drawn into parts of the dinosaur. The third design focused mainly on the technology aspect of the dinosaur. The RCX was the central piece of the design, and only a faint outline of a dinosaur shape can be seen.

Children were able to work in a collaborative way and quickly understood the importance of each other's tasks. For example, without prompting, when presenting their project to the other students in the classroom the builder began by saying that he was the builder but he could not build without the designer because he wouldn't know what to build. The programmer added that he could not program without the builder because he would have nothing to program.

Children this age are not always familiar with the LEGO pieces needed to construct an interactive kind of project, such as gears and motors. Therefore, the student-teacher provided scaffolding for the activity to help them learn by playing with the physical pieces. She also brought to the children a partially constructed and ill-built car and asked children to fix it. The goal was to avoid giving to the children an example for them to copy but to provide them with some guidance about the pieces needed to make the body of the dinosaur. This worked really well and children started to fix it through trial and error and to debug its program. The children used many different strategies and tested them during the process.

For example, during one test the body did not move, although the motors were both attached and the software program was properly working. They investigated the problem and found that the rear wheels were not positioned on a parallel axis. While struggling with ways to keep the dinosaur from falling over (it had only two wheels) one of the children made the observation: "If you put a dragging tail with wheels attached to the end it will make is stable” (Figure 7). The group accepted this and children engaged in an iterative design/building/programming process.

Figure 7. The dinosaur’s structure with its tail

Children also used *KidPix* to make a slide show to document their project and share it with others in the school community. This also served to assess the children’s understanding of the project. One of the children was the photographer in charge of using the digital camera to document the experience and edit the pictures to show what was really important in the experience. In the end the project was presented to the school community. It allowed children to show off all they had learned, and see their knowledge be put into immediate action, and produce something tangible.

The design journals were very important for helping the children compose their thoughts, for remembering what they were working on, and to see the progress they had made. The expert roles provided a great way to break the design process down to be more easily understood. The project was very successful and it could have been stretched out to cover the entire semester. Choosing a topic that was meaningful to them, such as the creation of a dinosaur to scare away the squirrels from their garden, was key to introducing them with easiness to the new technology.

The main problem that this student-teacher encountered was the lack of experience on behavioral management of the classroom and of individual personalities. Bringing a new concept and a new instructor into a classroom was extremely hard. This difficulty was magnified by the eagerness of the children to participate in an innovative experience using new, and very appealing, technology. Therefore the head teacher played an important role in helping her manage the classroom.

This experience demonstrates that young children are ready to be in charge of designing their own meaningful projects. As shown in this story, children went through a similar “learning by design” experience as the students-teachers went through in the course that gave birth to all of these projects. Children developed technological fluency by using laptops, digital cameras, and minidisk recorders. They learned how to program their robotic dinosaur and they explored introductory engineering concepts such as those required to build a LEGO structure. By developing technological fluency, they expressed themselves in many different ways through building, writing, taking pictures, and discussing their project. Most importantly they developed self-esteem and confidence in themselves as learners.

CONCLUSION

In this article a constructionist approach to introducing technology, in particular robotics, in the early childhood classroom is presented. Shown was how this approach is well suited since the basic four tenets of constructionism are already present in early education: learning by design, manipulating (computational) objects to think with, the exploration of powerful ideas, and the importance of self-reflection.

This article introduced a model for educating future teachers to integrate robotics in the classroom, through the use of LEGO Mindstorms and *ROBOLAB*, to develop technological fluency and to become designers of their own technologically-rich curriculum. The four learning stories presented in this article show how teachers identified powerful ideas, designed their own projects and, at the same time, provided opportunities for their own young students to learn by engaging in design experiences. These opportunities varied according to the capabilities and the developmental possibilities of the children.

For example, in the metamorphosis project, the student-teacher built and programmed the robotic heart. Children designed the different environments for the caterpillar to grow into a butterfly as well as engaged in a game to dress up the robotic heart with puppets, as it was traveling through the different environments. The three-year-old children who participated in this experience were not developmentally capable to learn more sophisticated aspects of programming and LEGO building. However, they were exposed to some of the possibilities that technology offered by taking an active role in the design process.

In the life cycle and the balance project the student-teachers were also in charge of the major part of the technological design. However, they created a technologically rich learning environment for the children; in which they were able to experiment and engage in inquiry-based learning and scientific predictions. As the student-teacher who built the motorized wheel to represent the life cycle realized, designing and building a robotic contraption helped him and his four-year-old students understand the cyclical aspect of the powerful life cycle idea.

The last project presented in this article shows how first and second graders engaged in a complete learning by design experience: They identified a real problem that affected them, such as squirrels eating their tulip garden, came up with a proposed solution such as designing, building, and programming a robotic dinosaur to scare the squirrels away and documented their project to be able to share it with others in their school community. This project was possible due to two important factors. First, the student-teacher had herself mastered the robotic technology used and therefore was comfortable in supporting her students through the learning process. Second, the activity was developmentally appropriate for those students, who were significantly older than the rest of the children who participated in the robotic experiences presented in the other learning stories.

The authors hope is that this article serves to identify good ways of introducing technology in early childhood classroom and provides a model for training early education teachers to develop not only technological-fluency but also a long-term vision of the possibilities of the constructionist approach. It is also hoped that early childhood professionals will discover the potential of using robotics in their classroom as a way to bridge both concrete and abstract explorations, and the benefits of using technologically-rich manipulatives with young children.

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