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Teaching Partnerships: Early Childhood and Engineering Students Teaching Math and Science Through Robotics

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This paper presents an innovative approach to introducing pre-service early childhood teachers to math, science and technology education. The approach involves the creation of partnerships between pre-service early childhood and engineering students to conceive, develop, implement and evaluate curriculum in the area of math, science and technology by using robotics and the engineering design process. In this paper we first present the theoretical framework for the creation of these partnerships. We then introduce an experience done at Tufts University in which three different forms of partnership models evolved: the collaborator's model, the external consultant's model and the developer's model. We also present different case studies from this experience and finally we conclude with some remarks and observations for making this work scalable and sustainable in other settings and universities.

KEY WORDS: early childhood; pre-service education; curriculum; robotics; math; science and technology.

THEORETICAL FRAMEWORK

The field of early childhood education (Pre-K to 2) agrees upon the need of introducing young children to MSTE (math, science, technology and engineering) (Clements, 1999; Seefeldt, 1999). However, the primary foci of professional development for early childhood teachers are on developmentally appropriate curriculum, emergent literacy, management strategies, and the importance of play to improve social and emotional development. Very few professional development programs focus on mathematics and science education in early childhood. Most curricula in these areas cover concepts such as numbers, operations, colors, shapes, the life cycle, and food groups, leaving behind foundational concepts such as the method of scientific inquiry, problem solving, and number sense. Although early childhood educators advocate helping young children become little scientists and little mathematicians (Chille and Britain, 1997), the reality of the classroom, the emphasis on literacy, and most importantly, the limitations in the formation of the teachers themselves in math and science, make it very hard to develop and implement innovative curricula that span beyond specific concepts to encompass ways of thinking and behaving in these disciplines.

The first National Education Goal defined by Congress and the nation's governors, "*All children will come to school ready to learn*," and recent findings from neuroscience have energized public support for early childhood education and have recognized that roots of later competence are established long before school age (Bowman, 1999). However, if early childhood teachers are not prepared to meet these new highs standards, and are not personally confident in their own abilities in math and science, it will be hard to implement the ambitious programs recommended by professional associations (Bredekamp and Copple, 1997). For example, according to the 1997 National Education Goals Report (National Education Goals Panel 1997), most teachers, while knowledgeable about reforms, do not

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exhibit in the classroom many of the behaviors suggested by those reforms.

Research has shown that early childhood educators have limited access and positive but temperate attitudes to the world of computers (Tsitouridou and Vryzas, 2003; Yildirim, 2000). Exposing teachers early on to technology is useful, however it is not sufficient to affect a change. Many wonderful teachers, who follow constructivist pedagogy, when faced with the challenge of using computers in the classroom, revert to instructionist ways of teaching and learning (Bers *et al.*, 2002). They lack the needed training and expertise to know how to integrate the technology with a constructivist curriculum and methodology. 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 is in part due to the lack of support at the beginning of their teaching careers through apprenticeship programs and other kinds of opportunities to interact with more experienced teachers. To address this problem, the National Commission on Teaching and America's Future (1996) recommended the funding of new mentoring programs that adhere to new teaching standards for science and mathematics for early childhood educator (Copley and Padron, 1999)

In this paper we claim that in order to effectively produce change in teachers' approaches to math and science education, it needs to start in their formative years. Although wonderful things can happen if teachers in the beginning of their careers are paired with mentors and provided with support, it is most likely that these beginner teachers will be mostly consumed by the everyday dynamics and challenges of being in a classroom and will have little mental or physical time to allocate to learning a new discipline and a new way of teaching about it. We suggest that the likelihood of improving success fundamentally increases if new programs and models are established in the pre-service years, when teachers are forming themselves. For this purpose, we present a partnership model in which pre-service early childhood teachers are paired up with engineering students to develop, implement and evaluate curricula in the areas of math, science and technology. The uniqueness of the model is that it uses robotics as a fundamental teaching tool for developing and implementing curriculum that integrates the content areas of math, science and technology.

ROBOTIC MANIPULATIVES

Since the 1800s, when Montessori and Fröbel developed their "manipulatives" or "gifts," there has been a strong emphasis on using tangible materials to help young children to engage in active inquiry by manipulating concrete objects to explore abstract concepts. 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, and at the same time, develop a deeper understanding of mathematical concepts such as number, size, and shape (Brosterman, 1997). 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 (Resnick, 1998).

It is within this tradition that robotics presents a wonderful opportunity to introduce children to the world of technology. Modern robotic construction kits provide opportunities for children to design and build interactive artifacts using materials from the world of engineering, such as gears, motors and sensors, and to engage in active enquiry by creating playful experiences (Bers *et al.*, 2002). They also provide an open-ended environment for teachers to develop innovative curriculum that integrates technology with different content areas.

Thirty states include technology education in their educational frameworks (Newberry, 2001); 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. The Massachusetts Science and Technology/Engineering Curriculum Framework (Massachusetts Department of Education, 2001) mandates the teaching of technology and engineering for all students in grades PreK-12.

Engineering education offers an excellent platform for project-based learning (Resnick *et al.*, 2000), that can motivate students to study math and science by illustrating relevant applications of theoretical principles in everyday contexts and promoting design processes including iteration and testing of alternatives in problem-solving. It also encompasses hands-on construction that can promote three-dimensional thinking and visualization, building students' technological literacy, which has become a component of basic literacy (Miaoulis, 2001; National Academy of Engineering & National Research Council, 2002; Roth, 1998; Sadler *et al.*, 2000). Engineering offers design-based activities which engage students in learning by applying concepts, skills and strategies to solve real-world problems that are relevant, epistemologically and personally meaningful (Papert, 1980; Resnick *et al.*, 1996). It provides a wonderful opportunity to integrate different areas of the curriculum, such as math and science, with the humanities and the social sciences (Benenson, 2001) and to motivate students to engage in learning math and science concepts, even when they identify themselves as "not good at" or "not interested in" this (Bers and Urrea, 2000).

Robotics is a rich tool for engaging teachers and young children in MSTE by providing opportunities for the active design of meaningful projects to explore and play with new concepts and ways of thinking in a constructivist way. These projects can combine manipulative materials they are familiar with, such as traditional Lego blocks, with new ones, such as the LEGO Mindstorms programmable brick (Martin *et al.*, 2000) and the ROBOLAB programming language (Portsmore, 1999). However, very few teachers have the experience and skills to conduct these kinds of activities. In the best cases, they know how to use some computer applications, but haven't developed true technological fluency to be able to learn, on their own, a new program, open-ended and sophisticated as to enable them and their students to program and design meaningful projects to meet their curricular needs.

This paper presents a methodology for teaching future teachers to integrate MSTE in the classroom by describing the experience of forming partnerships between engineering students and pre-service early childhood educators. In the next sections the paper describes the courses, the technology used and the way in which partnerships were formed. Later on, we describe both successful and unsuccessful learning experiences by presenting case studies. At the end, we evaluate the project both from the point of view of the early childhood pre-service educators and the engineering students. Finally we draw conclusions as well as present recommendations for extending these partnerships in other settings in a sustainable and scalable way.

COURSES DESCRIPTIONS

The formation of partnerships between pre-service early childhood educators and engineering students involved the collaboration of both authors, in charge of developing the curriculum for and teaching the following courses: CD 173 "Curriculum for Young Children: Math, Science and Technology," a required course for students seeking certification in the department of Child Development at Tufts University and EN 10 "Prototyping Home Robots," an introductory robotics class for engineering students.

CURRICULUM FOR YOUNG CHILDREN: MATH, SCIENCE AND TECHNOLOGY

The required course CD 173 "Curriculum for Young Children: Math, Science and Technology" came into existence in 2002, from the need of introducing early childhood teachers to theoretical, conceptual and technical aspects of math, science and technology education. In this context, student–teachers learn not only by doing, but also by designing new curriculum and new technologies and by testing them out in a classroom with close supervision from the faculty.

Students become technologically fluent by being exposed to learning diverse programming environments well-suited to engage young children in learning about math and problem solving, such as Logo (Clements and Sarana, 1993), techniques for critically evaluating educational software, and uses of technologies for science education in early childhood. Pre-service teachers also become designers of their own technologically rich curriculum in the areas of math and science by using the LEGO Mindstorms robotic construction kit and become fluent with the creation of websites by having to create an on-line portfolio documenting their experiences throughout the course.

CD173's curriculum is based on the four tenets of the constructionist philosophy of learning which 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. These four tenets have been previously described by Bers (Bers *et al.*, 2002):

1. *The belief in the constructionist approach to education.* This implies the need of setting up (computational) environments to help children and teachers learn by doing, by active inquiry and by playing with the (computational) materials around them in order to design and make meaningful projects to share with a community.

2. 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 (and later robotics), 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.
3. *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).
4. *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.

Students in CD173 engage in all four aspects described above: they learn by doing and by designing their own meaningful (curriculum) projects; they develop a robotic artifact, evaluate and improve it in an iterative process based on criteria established according their learning and teaching goals; they develop curriculum that integrates the use of the robotic artifact to help make concrete an abstract mathematical or scientific powerful idea, they implement the curriculum in their classroom experiences, and they engage in self-reflection by creating on-line portfolios.

The premise of the course is that if pre-service 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 or pedagogical approaches to the use computers in the classroom is not enough. They need to engage in a "learning by design" experience.

Previous experiences teaching CD173 showed that just one semester was a short time for pre-service teachers to develop the technological skills (and even more important, the vision of how the technology could be used in an innovative way) and at the same time to develop and implement a new curriculum for integrating MSTE in the early childhood classroom. The idea of forming partnerships with engineering students came as a way to solve some of these obstacles without putting aside any of the goals of the course.

PROTOTYPING HOME ROBOTS

At Tufts, all freshmen engineering students are required to take a half credit course each semester of their first year designed to give them a taste of "real" engineering so that they can understand the need to take the numerous math and science courses that dominate their first two years. The courses range from learning heat transfer through designing baking pans for cakes, to learning chemical engineering through the design of a microbrewery.

Prototyping Home Robots (EN 10) is a half credit course that gives students a hands-on introduction to robotics. Students design and build their own robots from LEGO Mindstorms materials (LEGO RCX and ROBOLAB software). Lectures in the class focus on building and programming skills, basic robotics history and terminology, introductory control theory, sensors and analog/digital conversions, and the design process. Each week during lab session students compete in a challenge. The students work in teams of two or three on challenges. Challenges range from simply building a robot to escape from a box to creating a network of robots that transport a lime from one end of the room to the other while traversing a series of obstacles. Teams receive one grade based on how well the robot they created as a group completed the assigned task.

The course always has a waiting list and is generally well received by the students. Students typically do well in the course, though they sometimes struggle with time management, team work, and some of the math involved with lecture topics. The collaboration with the pre-service early childhood teachers (CD 173) was added to EN 10 as a means of introducing engineering students to communication skills with a non-technical audience. In addition, we hoped to expose the engineering students to the issues of implementing hands-on projects in the classroom so that they would gain a better understanding of K-12 education. Tufts has the mission to increase citizenship among its undergraduates and, towards this end, several initiatives are aimed at increasing the connection between engineers entering the workforce and K-12 education (Portsmore *et al.*, 2003; Dunfey *et al.*, 2003).

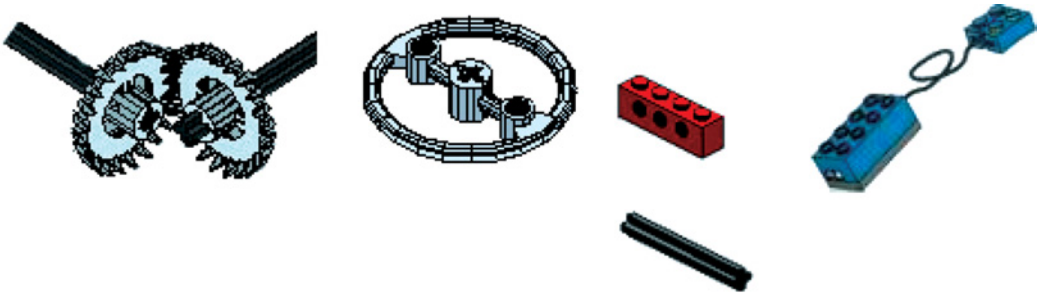

Fig. 1. LEGO technic pieces.

As part of the EN 10 course, groups of two to three engineering students were formed and each group was asked to select from a list of pre-service early childhood teachers' curriculum projects created in CD173 the one that they wanted to work on. The EN 10 students were told that they were expected to meet with their pre-service teachers partners and work on the designed curriculum for a period of 6–8 h. The EN 10 students were not graded on the quality of the product they created but on the write-up of the experience that they were required to submit at the end of the semester. This included documentation of their experience, pictures of their projects, and analysis of the process (what worked, what didn't work, what do you think the students learned).

THE ROBOTICS TECHNOLOGY: ROBOLAB AND THE LEGO MINDSTORMS KIT

The "LEGO Mindstorms for Schools" kits are the primary construction toolset for the two courses. The toolset is composed of 3 main components—Lego pieces, the LEGO RCX, and the ROBOLAB software. The LEGO pieces in the "LEGO Mindstorms for Schools" are from the LEGO Technic line (Fig. 1). This line includes the standard LEGO pieces most people are familiar with including bricks, beams, and plates. In addition, it has a range of engineering elements including motors, sensors, gears, cams, pulleys, and axles (Fig. 1).

The LEGO RCX is a LEGO brick with an embedded microprocessor (Fig. 2). The RCX has three outputs for controlling motors and lights and three inputs for gathering data.

To use the RCX in a robotic creation it must be programmed as to when to turn motors on and off, when to collect information, etc. Multiple environments for programming the RCX have emerged. The one used in courses at Tufts is entitled ROBOLAB and was developed via a partnership between Tufts University, National Instruments, and LEGO Education. ROBOLAB provides a graphical way to program the RCX on both PC and Mac platforms. Powered by National Instrument's LabVIEW, ROBOLAB allows users to program by connecting icons that represent commands. ROBOLAB has a tiered interface with multiple levels to allow different entry points for students of different ages and abilities. The lower levels entitled Pilot (Fig. 3), allows children as young as four to program while the higher level entitled Inventor has been used in elementary school through college.

At the highest level (Inventor–Fig. 4), ROBOLAB allows users to control all the capabilities of the RCX and develop sophisticated robotic algorithms.

Fig. 2. The RCX.

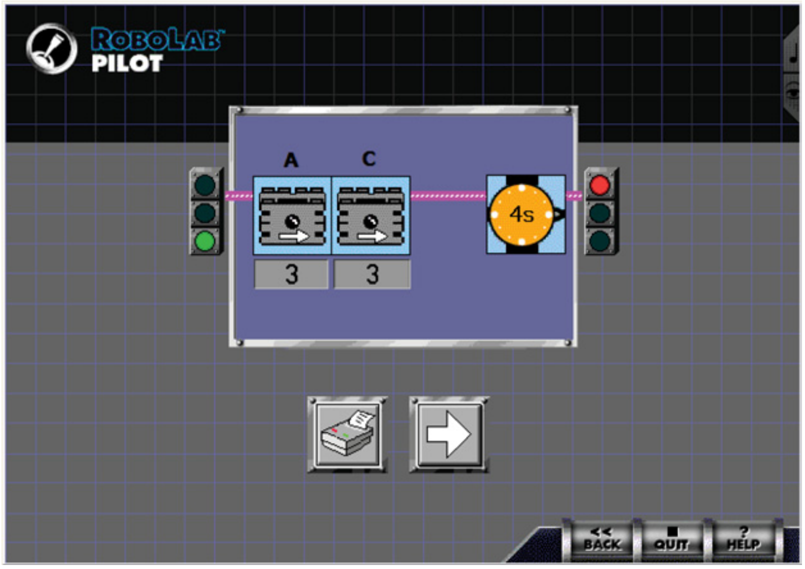

Fig. 3. A simple pilot level program to drive a car forward for 4 s.

FORMATION OF PARTNERSHIPS: EXPERT & EDUCATION CONNECTIONS

The formation of connections between experts in math, science and engineering and educators is not a new idea. Industries that rely heavily on a workforce with math, science, and engineering knowledge are significant supporters of K-12 education. Many have generous grant programs, support and sponsor existing programs (FIRST, Engineer's Week, Explorer Scouts, etc.), and encourage employees to volunteer to work with students in the local community as mentors or tutors. Several companies, like Lockheed Martin (2004), Intel (2004), Rocketdyne (2004) and National Instruments (2004), 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 via employee volunteers to teachers

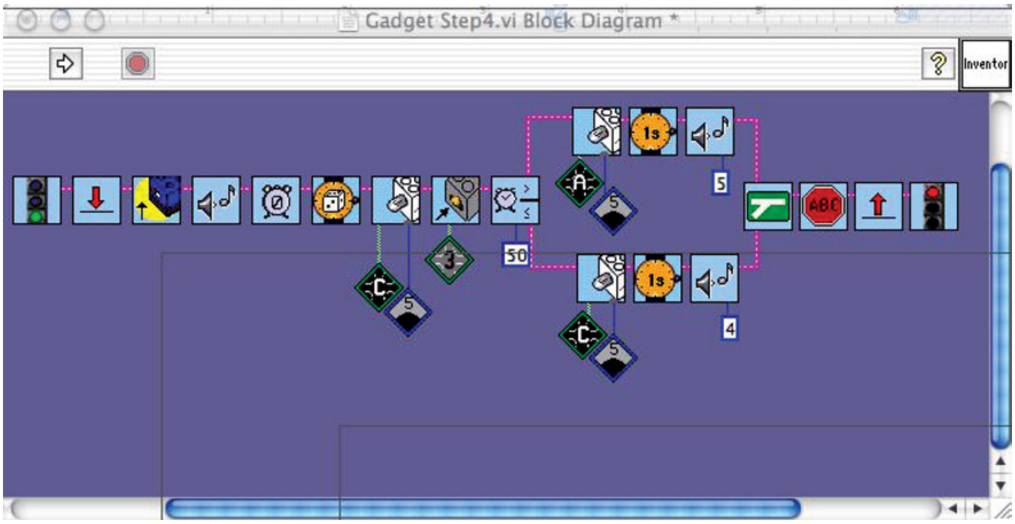

Fig. 4. Advanced Inventor programs are structured similarly to flow charts.

who participate in DTEACH summer workshops (sponsored in part by National Instruments). Tech Coprs (2003), a national non profit, 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. The GK-12 program provides tuition waivers and stipends to graduate students fellows pursuing advanced degrees in science, math, or engineering in exchange for the students spending 15 h per week in K-12 classrooms. There are 118 GK-12 sites at universities and colleges spread across 41 states. The program estimates that between 2000 and 2004, 993 graduate students have been involved helping to reach 1195 K-12 teachers (National Science Foundation, 2004). Individual sites have reported the partnership as having a positive impact on the teachers and students as well as the graduate fellows (Lyons *et al.*, 2003; Dunfey *et al.*, 2003; Llewellyn *et al.*, 2002).

The quantity and success (though there are limited reports) to date indicate that this model is a useful way of supporting education and providing citizenship opportunities to those with technical skills. However, while many undergraduates in technical fields volunteer on their own time in school and after school settings, this type of partnership has not been replicated at the college level as part of required coursework. Starting these type of partnerships earlier has the potential to help pre-service teachers develop skills and confidence and give those with technical background an opportunity to work with educators to become more fully engaged civic citizens and understand the education system and challenges in our country.

PARTNERSHIPS: PRE-SERVICE TEACHERS AND ENGINEERING STUDENTS

The requirement for students in both courses CD173 and EN10 was to form partnerships and to contact each other. We did not specify any ways in which partnerships should evolve or partners work together. The goal of having this flexible approach was to observe what models would evolve and to elucidate the pros and cons of each model so to later propose a scalable and sustainable approach for this methodology of teaching. We observed three different ways in which partnerships formed and, based on the role assumed by the engineering students, we labeled them as the following models:

Developer's Model

In this technical outsourcing model, pre-service teachers developed the curriculum with no input from the engineering students and then handed out the technical implementation to the engineers. Pre-service teachers were not familiar with the inner working of the resulting robotic artifact and only knew how to operate it, but not how to fix or adapt it. Pre-service teachers assumed that everything on the technical realm would be done for them and therefore did not take any responsibility in understanding or participating in the robotic development process. For example, a very experienced teacher taking the class to strengthen his knowledge about math, science and technology complained "*my particular partners were not that on the ball, wasted time, and really had to be pushed. What they came up with was actually very clever and powerful, but because they hadn't tested it adequately (didn't have a working prototype when they promised) the project really did not succeed as we envisioned.*" In the mind of this teacher, it was the job of the engineering students to do it all, with respect to implementing and testing the technology, and his job to actually take the project to the classroom. In his conceptualization of the division of labor between educators and engineering students, this student completely forgot that his own reason for taking the course was to develop a better understanding of technology. This was commonly observed in pre-service teachers who initially claimed that their main goal for taking the course was to "learn more about technology," but who after being exposed to it, didn't want to invest the time and effort needed.

External Consultant' Mode

In this mode, pre-service teachers developed the curriculum with minimal, but some, input from the engineering students and worked with the engineers to craft basic robotic artifact that the engineers would further develop into a complex mechanism. In this model, the engineering students were sometimes present in the classrooms in which their robotic tools were used by the young students, but not always. According to pre-service teachers, this partnership model was successful. A young woman expressed in her evaluation: "*it allowed me to think creatively about how to integrate the robotics into my curriculum without the anxiety of knowing I had to make it all by myself.*" As another student pointed out it was a good experience because having to communicate to the engineers *"exactly what I needed and wanted from them forced me to engage in a very precise mode of communication,"* which is sometimes used in writing technical specifications and technical documents but it is not frequently used by humanities or education students. One of the most successful cases within this model, was a pre-service teacher who conceived a curriculum unit, as well as a robotic artifact, to enable her young first graders to collect and analyze data gathered by a light sensor embedded in a robotic car. Although the engineering students were not involved in the design of the curriculum unit, they played a major role in helping this pre-service teacher not only to design the robot but also to consult with her regarding ways in which robotics could be used for data collection purposes.

Collaborators Model

With this model, a close collaboration was established between the pre-service teachers and the engineering students in which both the curriculum and the technology were co-developed. Within this model, the engineers were also partners in the implementation of the curriculum in the school by serving as co-teachers. This proved to be the most successful, time consuming and difficult model of collaboration for both pre-service and engineering students. A pre-service student working with kindergartners who collaborated with the engineering students to help the children themselves to design, build and program robotic cars reflected on her evaluation: *"We needed more time with the engineering students to discuss possibilities, plan curriculum, try out ideas and then successfully use them in the classroom. I am used to working on a team, so I was not comfortable planning a piece of my curriculum and then handing it over to someone else to design. I wanted all three of us to be involved in the planning, design and implementation process. I liked the idea of working with students with different backgrounds, unfortunately I did not get the same feeling from them at the beginning, they were not expecting to work with me during all stages of the project. They wanted to know what I needed so they could make it for me, it took several meetings with them to have them understand why I wanted to be there for the whole process and eventually we ended up on the same page."* These students ended up with the design of a clever curriculum unit in which children first wrote a letter to the engineering students asking them to design a Lego robot car to solve a specific problem in their kindergarten classroom. The engineering students sent them back a letter with technical specifications, written at a level that kindergartners would be to be able to understand, with a basic already built car that needed to be finished by the young children. At this point the engineering students came into the classroom and helped the children, and the pre-service teacher, to explore how to best complete the car and program its behavior.

From these three spontaneous models in which partnerships evolved, 27% of the resulting curriculum projects were in the Developer's model, 46% were in the External Consultants model, and the final 27% on the Collaborators model. For students in both the child development and the engineering departments, the collaborator's model proved to be most effective, but also the most time consuming. It involved a major commitment but also returned the highest benefits. The External Consultants model was the most frequently occurring model as it seemed to allow both sides to utilize their existing knowledge most efficiently and minimize the time commitment.

Within these projects and partnerships, beyond the particular goals of the CD173 course, child development students learned how to communicate with engineers in a precise way, and how to collaborate with people from a very different discipline who may bring a different way of approaching problem solving. Engineers developed communication skills for defining a project and developing a solution for a non technical audience. They also negotiated issues of time management, and division of labor. Both groups reported developing strategies for working in a team, iterating through the design process, and balancing design requirements (the trade off of functionality vs. reliability).

CASE STUDIES

In the following sections, we provide case studies for each of the three partnerships models presented earlier. The case studies were selected because they show the learning experiences of both child development and engineering students and reflect the main characteristics that we have identified for each partnership model. They also provide an insight into the complex technologically rich curriculum designed by early childhood students seeking certification.

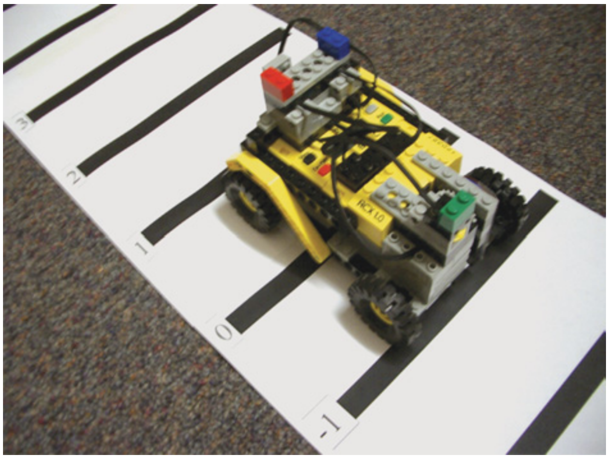

Fig. 5. Car on number line.

COLLABORATOR'S MODEL: ADDITION AND SUBTRACTION

Josh and Ace, two freshmen engineering students, worked with Laura, a pre-service teacher in a first grade classroom developing and implementing her curriculum in an urban setting. Laura was trying to teacher her young students the concept of addition and subtraction. She wanted the engineering students to help her create a visual and tangible representation for the concept for the children to interact with. After meeting, the group decided that Josh and Ace would build cars for students that would travel up or down a number line based (Fig. 5) on student's inputs.

The cars would have two inputs (touch sensors) where the first grade students could enter numbers by pressing a touch sensor multiple times (Fig. 6). The cars would have a third touch sensor that would serve as the "equals sign" to signal the robot to add the first two inputs together and initiate movement up or down the number line. For example if the button under the blue block on the car was pressed two times and the button under the red block was pressed three times, when the third button on the back of the vehicle was pressed the car would travel to the number 5 on the number line.

During the design process, the engineering students reported a collaborative relationship with their partner, where she pointed out issues that would come up in the classroom and features that would help her young students learn.

> She asked that we implement sound so that the children would be receiving auditory feedback when they entered a number and each time a line/number was crossed. With auditory feedback they would not accidentally miss-hit the touch sensors without knowing it. By beeping after each line, the child would be able to keep track of the numbers entered and their sum. Laura also suggested that we limit the numbers to be equal or less than 10. If this constraint was not added, a student could repeatedly hit the touch sensor upwards toward 50 times and the car would never stop.

The challenge of the curriculum unit designed by Laura and her partners was to use a new technology to make the concepts of addition and subtraction "tangible." On the one hand, these concepts are difficult for young children to grasp but quite simple for the engineers to understand. However, building and programming cars to demonstrate addition and subtraction was not trivial. The engineering students needed to design a vehicle that was robust enough for first graders to use. They also needed to make the interface for using it easy to understand for young students. Their program also needed to account for different ways the students might interact with the car. Josh and Ace spent much time refining their concept and working to improve the reliability and accuracy of their vehicle. They added reinforcements to their vehicle, color-coded the buttons, and developed sophisticated programming algorithms to prevent first-grade students from entering number combinations the vehicle was unable to demonstrate. The project was equal in time and scope to the more advanced challenges in the EN 10 course because it actually had to be used by children and hence needed to be robust and account for different interactions.

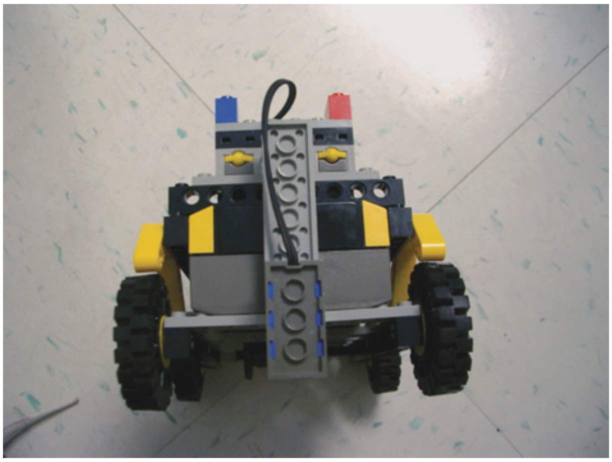

Fig. 6. Close-up of number car. The yellow buttons under the red and blue blocks were used to enter the two numbers to be added together.

The evaluation papers of the engineering students were positive as they showed a sense of accomplishment. They also indicated they enjoyed the education issues involved in the design of their project (such as design considerations, developing and implementing curriculum and engaging in close collaboration with a pre-service teacher) and engaging in a real engineering design process.

> I was really impressed at how well our project worked out. . . . We learned throughout going over the lesson plans about the different ways in which addition is taught and in that sense we learned quite a bit about the educational process. I really liked how we were doing what real engineers have to do. We had to design a product, then market it, convince Laura that it was the correct thing for her lesson plans and finally actually build that product. That was the most fun part of the project for me—the concept that I was actually doing a complete engineering project from beginning to end.

From the perspective of the child development student, the project was also very successful because she was able to design an addition and subtraction curriculum unit that incorporated the use of new technologies in an innovative and engaging way. In her final paper she wrote:

> This experience has made me want to include technology such as the RCX in every unit I create in the future. Unfortunately, I am also aware that I would have not been able to create the program for the RCX and build each car without the help of the engineers. The process was extremely time consuming, especially since I wanted to use eight RCXs. If I am not able to incorporate RCXs in the same way due to time, I hope to incorporate the use of simple RCX cars to teach other concepts such as programming and attempt to integrate them into other curriculum areas.

EXTERNAL CONSULTANTS MODEL: SIMON SAYS . . . PATTERNS

Allison, a child development student, worked with an advanced engineering student (the Teaching Assistant for the EN 10 course) on her project. She had developed three different lessons to promote the discovery of patterns and to increase students' level of understanding of this mathematical concept. She began with a lesson introducing the structure, predictability and commonality of patterns in the world around. She then continued with a lesson during which the children applied their knowledge of patterns to numbers by using manipulative materials. Finally she extended this by providing a technological environment, a gingerbread robot named Simon, in which children were given the opportunity to physically act out and describe patterns to each other and to consider similarities and differences between different patterns. Simon would move different parts of its body in varying ways to create a number of patterned sequences that the kids would then be able to act out. Through meeting with the engineering student she learned more about the Robolab program, and decided that the robot would move both its arms and legs in various four or five movement sequences.

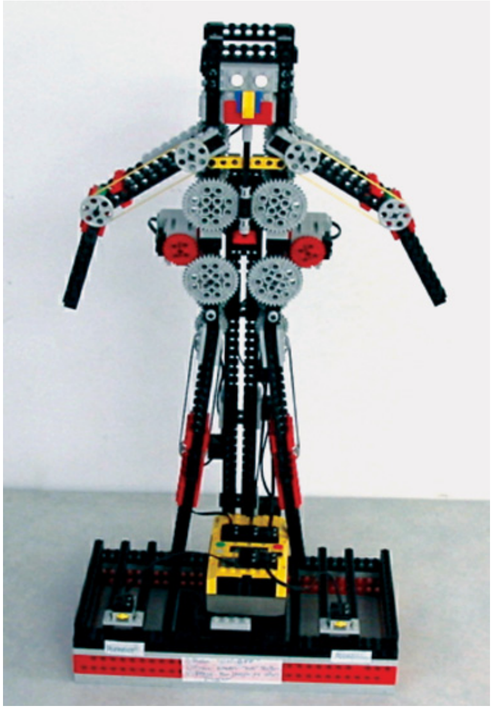

Fig. 7. Simon could move each of his limbs and was programmed with five different patterns.

Allison was not able to participate in the actual design process of Simon (Fig. 7), and only corresponded via e-mail with the engineering student, who built the robot in 3 h and then used Robolab to program the sequence to govern the movement of each limb. Allison was able to describe the technical details of the building and the programming done by the engineering students, but wasn't able to fully understand it as to be able to modify it.

When Allison used Simon in the classroom the activity evolved fairly closely to what she had initially expected. But she also discovered that children were interested not only in the patterns of movement of Simon, but also on the different parts of the robot and how the gears and rubber bands worked together to get the body parts to move. After the activity, Allison reflected in her paper "*The children were interested in learning about gears and the functioning of technology, which helped to motivate them as they engaged in the activity. For this activity, the children did not take part in the engineering design or programming, however, each child did have a chance to take charge of controlling the robot's movements, something that the children seemed to really enjoy. If I were to do this project again I might have the children participate more in the design process.*"

This observation lead her to express that she would also like to be more involved in the design process next time. Although her project was successful and matched her original plan, Allison felt that if she had collaborated more closely with the engineering student, and invited him into her classroom, she would have been able to branch her curriculum to satisfy the children's curiosity and to dive deeper into more sophisticated technological concepts that children wanted to know about. From the engineering student's perspective Simon was an interesting challenge. *"It was a very cool project because it was technically challenging for me to create arms and legs that looked and moved realistically. I've built a number of high end projects and I was surprised how drawn everyone was to this one. Everyone who saw me building it stopped to check it out."* He also expressed that the challenge was well formed so he had little need to be in close contact with his partner although it could have been helpful. *"I realized that I shouldn't have Simon do anything the kids couldn't do—like have both feet off the floor at the same time. That is one of those specifications I could have forgotten since I haven't worked with kids that much."*

DEVELOPER'S MODEL: THE TORTOISE AND THE HARE

Edith is a pre-service teacher doing her practicum experience in a combined kindergarten and first grade classroom. She decided to create a curriculum unit "The Tortoise and the Hare" to teach students how to quickly problem solve and to understand that when problem-solving there are often many ways to get to the same solution. Her curriculum was composed of three distinct activities that encouraged children to find multiple ways to add to the same number. Two main components of the project were to integrate stories from Aesop's Fables into the math curriculum and to utilize Lego Robots to conduct a Tortoise and the Hare race.There were two primary goals for this activity. The first goal was to integrate technology into the classroom through the use of Robolab and Lego programmable bricks with the help of the engineering students. The second was for the children to understand that there are multiple ways to add to the same number. She planned the unit on her own and initially conceived the role of the Engineering students as partners *"who will help me bring my ideas about the tortoise and the hare race come to life. The Tortoise will be programmed to walk a certain amount of steps to reach the finish line. Each time he takes a step something noticeable will happen that will let the children know what a step looks or sounds like (i.e., a beep, a flash of light). The Hare will be programmed to move the same amount of steps as the Tortoise. But, the Hare will always take one nap in the middle of the race causing the number to be split into two. So, five would be split into four and one, two and three, three and two, one and four. The nap will be signified by some sort of sound or light. While the Hare is taking a nap the children will have to figure out how many steps the Hare needs to go to catch up with the Tortoise."*

Edith planned to begin the activity by telling children the fable and later she was hoping to explain how the technology worked and to conduct the counting challenge (e.g. how many steps the Hare needs to go after his nap to catch up to the Tortoise?). She was planning to give each child five unifix cubes to keep in front of him or her to help them with their task by using the cubes or their fingers to figure out how many more steps the Hare needs to take. (Fig. 8)

Unfortunately the implementation of this activity in the classroom looked very different from this initial plan. Edith attributes this "*to a number of 'technical difficulties' in the construction of the Tortoise and the Hare. The carpeted floors in my classroom turned out to be the cause of one problem because the Tortoise could only walk on smooth surfaces. The Hare, on the other hand, was so loud when it moved on hard surfaces that it could only be used on the carpeting or it would distract the other children at work. The quiet volume of the beeps signifying steps also posed a problem in a busy K/1 classroom."* However all of these problems could have been avoided had Edith been involved in the full cycle of the design/implementation process of the robotic project and had explained to the engineering students (who were clueless about the particular atmosphere of

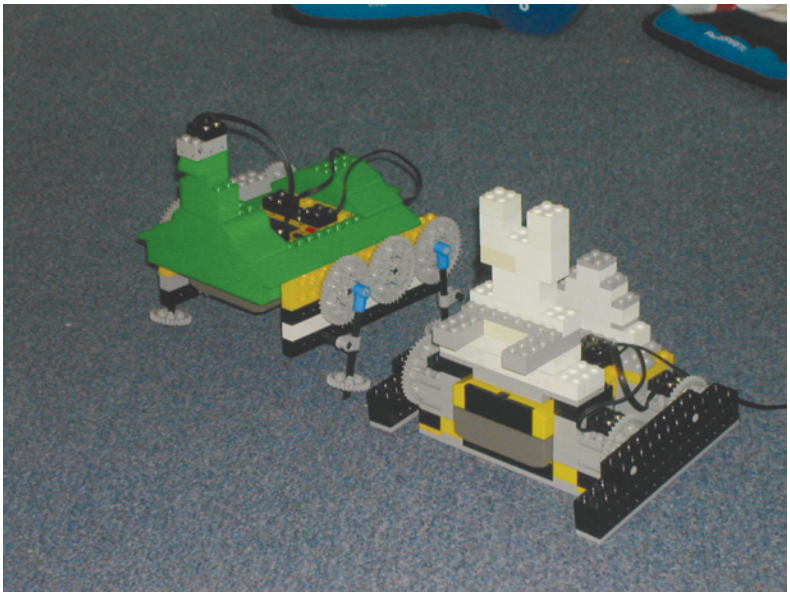

Fig. 8. The Tortoise and the Hare.

an early childhood classroom) the context in which these robots were going to be used.

The lack of communication between both and the developer model of partnership that only involved engineers in the technical implementation phase of the project was detrimental to the success of the project as the pre-service teacher had originally envisioned it. *"I found it challenging to get my ideas across to the engineering students despite what I thought to be a clear explanation of my design ideas goals. It seemed difficult for them to imagine how the activity was going to be run in the classroom and what I would need the robots to do in order for them to be useful. I ultimately was not able to get the Tortoise and the Hare to do what I wanted them to for the math activity to be successful and meet my goals."* The engineers echoed this communication problem but from a different perspective *"Working on this project was a crash course in communicating complex ideas in a simple way. Edith, for example, had not had much experience with ROBOLAB, so it took quite a bit of explaining and devising new ways to explain why I was having trouble figuring out the distance beep problem"*

Although there were problems with the robots and the planned activity did not succeed, Edith was able to turn this into a positive learning experience.

> "Just as the children engaged in problem solving, so did I. This experience has helped me to modify curriculum plans quickly and to work with the materials that I have available to me. Although it was frustrating and disappointing that the technology did not work as I hoped it would, I challenged myself to give children a meaningful learning experience without following my lesson plan." This skill, the ability to quickly accommodate and change plans, is one of the aspects that most pre-service teachers fear most about using technology. However, since technology doesn't always work as expected, overcoming this fear is one of the first requirements for teachers to successfully integrate new technologies in the curriculum.

EVALUATING PARTNERSHIPS

Most of the evaluations of the partnership experience for both the pre-service and the engineering students were positive. On the pre-service teachers evaluations, two main ideas were recurrent: (1) early childhood educators found themselves challenged by the need to communicate with others in a different field of study. Most of the evaluations resonate with the following statement made by a pre-service teacher: *"I had to do a lot of translating for them [the engineering students]; and they had to do the same with me"*. And, (2) early childhood educators were able to push further the notion of developing technologically rich curriculum to explore deep ideas in math and science trough the use of robotics. For example, a child development student who created a robot with a camera on top so it would provide new perspectives on things around the classroom (the car's point of view) and enable young children to discuss spatial relations concepts, wrote in her evaluation: *"The technology component of this curriculum project, was by far the component about which I was most uncertain. It was also, by far, the most successful activity I did with the children. . . . I am not technologically fluent and I approach technology with both apprehension and low expectations. Before I took this class, I was also thoroughly unconvinced of the power of technology as an educational tool. Though the class readings and discussion, I became convinced of its efficacy. In fact, by the time I had to design the project, I felt I knew enough about it to tell a truly powerful use of educational technology from a merely interesting or fun one."*

On the engineering side, the project was intended to improve the engineering students' communication skills and understanding of K-12 education. However, it also provided most students with an authentic engineering design challenge — complete with prototyping, redesigning, and marketing of their creation to a non-technical consumer. This is nearly impossible to reproduce inside the engineering classroom as the instructor is not a real consumer and generally has a technical background. Nearly all the students' papers indicated how much they liked engaging in an authentic design process where they truly were the experts. Having real consumers, however, introduced a lot of variability and equity issues. The projects were not all on the same level of difficulty and the child development students had different levels of interest and demands in the project.

Although forming partnerships proved to be successful, some of the problems arose because pre-service teachers complained that engineering students were not used to having to get ready on time for a "real project" that would be happening with "real people" in a young classroom. Advanced preparation is one of the distinctive features that separates a good from a bad teacher, but engineering students were not aware of this. Therefore, when pre-service teachers engaged in explaining this out, it provided an opportunity for engineering student to learn about the responsibilities involved in being an educator.

RECOMMENDATIONS FOR FUTURE WORK

The pilot project presented in this paper provided insight into ways to improve the concept of forming partnerships between pre-service early childhood educators and engineering students.

Project Requirements

The success of the Collaborator partnerships model indicate that the project should be presented to students as more of a joint project where students from each discipline are expected to contribute to the classroom curriculum and the technology—i.e. students from each setting are designers of the technology and the curriculum. Defining the project as a mutual undertaking will help to promote the two types of models (External Consultant and Collaborative) that were most beneficial to both sets of students in terms of creating a final project that they were both involved in.

Time

The projects were completed completely outside of class, which made it difficult for students to find time to meet. First and second year engineering students have very different schedules than third and fourth year students involved in a pre-service teaching program. Having additional class periods dedicated to the project would help to alleviate this issue. The project should also be introduced earlier in the semester. With delays and other problems, some projects were being done at the same time as the final project (for the engineers) or the final paper (for the child development students). This added a level of stress that created discontent amongst the students. Ideally, the classes would take place in the same time block to facilitate collaboration.

Structure

During the pilot the instructors did not meet with groups or intervene in any way unless requested to. This worked well for some groups but many groups could have benefited from more discussions with instructors about how to proceed with their project. The younger engineering students, in particular, needed more guidance about how to work with other students and how to keep their project on schedule. Meetings between groups and instructors would also help to address some of the personality and communication conflicts that arose. Additional "checkpoints" should also be implemented—such as a draft of the curriculum concept that the instructor could review or a basic working prototype.

CONCLUSIONS

The model of using partnerships has enormous potential for sustainability as the courses are required parts of their respective departments and offered on an annual basis. This ensures an ample supply of students and departmental support and funding for instructors and teaching assistants. The sustainability factors also would allow the course to be replicated at other institutions which have engineering and teacher preparation programs as the start-up costs are low. While the LEGO materials used in these partnerships are a costly investment, the model could be used with less expensive materials (paper clips, tape, paper) or with computer software.

The less successful projects helped to indicate how these partnerships need to be structured and monitored in the future. While the students involved in these projects were less enthusiastic about their results, their results clearly illustrated issues that face many educators implementing technology in the classroom, such as understanding and access to technology, support in the classroom, etc.

The successful projects in this pilot demonstrate the power of the partnership between students in different disciplines. The projects created by these partnerships could not have been designed, created and tested in real classrooms within the constraints of a college course by students from either class on their own. The blending of skills made it possible for cutting edge projects to be developed and implemented in a relatively short period of time. This allowed the pre-service early childhood teachers to see the potential offered by technology and what they would need to know to continue using it. They also were able to design with technology with the safety net of experts (the engineering students). From the engineers' perspective, they were engaged in a real engineering experience with actual end-users. They had to meet the demands of their "clients" and convey technical knowledge and limitations. They also gained insight into the educational system and the issues involved in incorporating technology into the classroom. The overwhelmingly positive comments from students involved in successful projects and the quality of their work indicate that the partnerships have tremendous potential to offer learning experiences to both sets of students.

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