An Examination of Early Elementary Students' Approaches to Engineering

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A five-week interactive workshop gave us the opportunity to study the engineering learning processes of early elementary children, allowing us to gain a sense of their innate engineering abilities and the processes they could be taught in the context of the Project Inter-actions study at Tufts University Department of Child Development. Forty children participated in the research, split into four groups of 10 each, each group participating in 5 workshop sessions of 2 hours each. In two of the groups, the children worked on self-generated engineering projects by themselves, while the other half worked with their parents to generate and complete the project. The children used a robotic construction kit composed of Lego pieces, an RCX computerized Lego brick, and the ROBOLAB computer software to bring their projects to life. Children also kept a design journal, allowing an understanding of their thought process. Children were videotaped during the workshop and completed questionnaires before and after the experience. All of this data allows us to examine areas in the design process where children are innately strong, and areas in which structured instruction aided in the children's conception of engineering. Instruction could come in the form of the short teacher lessons that occurred in the beginning of each workshop, individualized teacher interaction, or interaction between parent and child. Understanding the role of the adults in the workshops, either parents or instructors, would allow for greater generalization to other learning environments where young children are practicing engineering and demonstrate that five year olds are capable of gaining a greater appreciation and understanding of the engineering process.

Introduction

Recently, there has been an increasing effort to bring engineering teaching into the lives of young children. The Massachusetts State Frameworks introduce children to engineering in the first grade, and as such, it is important to understand the teaching methods that lead to successful understanding of engineering and the design process. Project Inter-Actions at Tufts University provided the opportunity to explore engineering teaching and explorations in a contained environment. It is our belief that young students can engage in thoughtful engineering pursuits by exploring personal powerful ideas, and benefit the most from the opportunity to think through various problems with one on one interaction.

The Massachusetts State Science and Technology/Engineering Curriculum Framework[1] is to allow children to draw upon the specific skills that these disciplines require as they conduct lives in their society. Interestingly, the Massachusetts Curriculum Framework defines engineering and technology as the design of "useful devices or materials," however, in this research we note that the utility of the appliances the children design goes little beyond their own highly individualized imaginative worlds. That is not to say that the children are not acquiring useful skills in the process, we note that children learn about simple machines, the design process, and computer programming as they go about their explorations.

Our beliefs here are in the tradition of Papert[2] who put forth the notion of powerful ideas. Simply put, powerful ideas are those that come from within the learner, ideas of personal meaning that one explores simply to fuel his own curiosity. We also note that in this workshop, a highly aesthetic view of engineering emerges in children's projects. For young children, style and fun are traits to be utilized in an engineering exploration. This project is also guided by previous work in instructing children in engineering. Bers et al[3] have noted that constructionist methodologies often break down in classroom settings when teachers are confronted with computers as teaching tools. In these workshops, we hope to be able to provide all of our participants an immersive constructionist experience. A pilot study of Project Inter-Actions[4] showed that in our environment, very young children could learn along non-experts and develop some understanding of engineering processes.

We also hold the role of play[5] in high regard. Children at a young age use play to learn about the world around them, and thus it becomes a powerful pedagogical tool. We strive for our workshop to be fun, the lessons that children learn will resonate more if they laugh as they learn. This isn't a matter of having teachers tell good jokes to the children, it's a serious endeavor that allows for children to engage in engineering on the level they feel comfortable, and to turn it into a tool for their own enjoyment.

This paper first presents a description of Project-Interactions and the methods used. We then continue into the results of the project, presenting the final projects that each of the children have built. Here, we just provide an overview of the outcomes; we later discuss several of the projects in greater detail. From this, we move into how this will drive our future research.

Methods

Project Interaction consisted of five, one-hour workshops for each of the groups participating. There were four groups; two consisting of 10 children and two that consisted of 10 sets of a child and a guardian. There were two separate head teachers, who had jointly worked in a pilot workshop and with similar curriculums. These two teachers were each assisted by three aides, for a total of four teachers in each session. Children were recruited from local first and second grades in public and private schools and were between 5 and 7 years old; because parents needed to elect for their child to participate the sample was self selecting. Children were given robotic kits that consisted of an RCX programmable Lego brick, two Lego motors, two Lego lamps, two Lego touch sensors, one Lego light sensor, and a large amount of assorted Lego pieces that could be used for building. Additionally, the participants had access to a large cache of spare Lego building parts and electronics at their disposal.

Participants moved through a structured curriculum that consisted of time to work in a large group and time to work in pairs. In parent-child workshops, the parent-child group represented the pair, while in children-only workshops each child selected a partner with whom to work. The first session was dedicated to gaining familiarity with the Lego pieces, groups were simply encouraged to play. In the second session programming concepts were introduced. Rather than allowing for a successive string of events, we allowed children to gain experience with the 'wait-for' Robolab construct. The idea surrounding wait-for is such that the robot will wait for an event before continuing to include waiting for time or waiting for some sort of sensor input. We subsequently introduced the idea of sensors, pointing out that the robot can interact with the environment around it.

We also strived to create a metaphor for the children to relate to the robot and the programming language. We referred to the RCX brick as the robot's brain. Light sensors were referred to as eyes, and touch sensors as hands, and motors as feet. Once a child begins to use the more standard vocabulary, we embrace this and do not 'talk down'.

Our third session saw more practice with programming and we introduced the idea of a 'final project'. For this challenge, children were free to build any object of their choosing. They had the support of teachers, but no guided group time. Exceptions would be made if a child discovered something interesting, and they would share this discovery with the group. We spent the entire two sessions in entirety working on the final projects, and children also had the opportunity to come to Tufts to receive additional help if their schedule could accommodate it during "Repair Shop" sessions. On the final day the child's entire family was invited in to see their work as well as that of the rest of the group.

Data was collected by videotape, questionnaires, and narratives submitted by teachers and aides. For each session, there was a stationary camera set up in our room, as well as a roving camera manned by an interviewer. Separate from the teachers and aides, the interviewer would be responsible for asking children and parents questions about their progress. Teacher narratives were submitted immediately after each session, and questionnaires were filled out before and after the workshop.

Results

Later, we'll discuss implications of our data collection methods; however, our ability to discern results is somewhat limited. Examining whole group results, in particular, is difficult, although we can look at trends in the final projects, when the participants were acting wholly independently, to attempt to understand to what directions our teaching led. The questionnaire data is limited to parent-child groups; in the child-only groups we saw inconsistencies with the respondent, who was sometimes the child participant and sometimes the parent.

Parent-Child Group 1:

- A Mess Machine uses gears to rotate a catapult into position. The group connects a smaller gear to a large gear to slow down the rotation and increase power, and a long arm connected to a lever to fling a paper ball across the room.
- A Castle uses motors to open and close a drawbridge. A program is written so that pressing a button activated the door, and the castle itself is a tall, colorful lego structure.
- Uncle Feather (based on a bird from Judy Blume's Fudge books) is a remote control bird. It uses two motors connected to axles to control steering. Another motor controls the flapping of the wings. Interestingly, all of the motors are mounted such that the direction of spin must be changed through gears to deliver power. The RCX was programmed to respond to three touch sensors as buttons. Pressing them controls the motion and flapping of the creation.
- Toyagumon was an ambitious project to build Digimon characters out of Legos. The grasp of imagination exceeded the possibilities in the time constraints of the workshop, although the group built very rich structures they were never able to put together a mechanized robot.
- The Basketball Player uses two motors to allow an arm to slam-dunk a make believe basketball (a crumpled up piece of paper) into a lego basket. One motor lowers an arm, allowing the robot to 'jump' while another controls a lever that slams the ball into the basket.
- The Birdie is a two motor controlled car that reacts to light. When it sees light, it gets 'scared' and runs and hides.

- The Robotic Man uses a gear and motor system that runs an intricate system of lever legs that allow the robot to walk.
- The Catapulting Car is a combination of a car, controlled by two motors, and geared for peed, and a catapult that can send an object flying into the air.
- The Paddle Boat is a long chain of gears attached to two motors that attempts to drive a large paddle. The RCX is mounted on a floatable foam, however, the group failed to get the paddle to spin.

Parent-Child Group 2

- The Vit-Vit features a paper mache mask fitted over a car controlled by two motors. The car is programmed to go for a specified amount of time.
- The Picker-Upper is a car that drives via a motor connected to an axle in the rear via gearing. In the front, another motor is connected to a gear that lifts an arm picking up an object in its path. The robot uses a program to drive for a specified amount of time and then use its arm.
- Miss Violinist uses gears to make an arm appear as a bow playing a violin. The entire structure is attached to a hand made doll, and the RCX is programmed to play Ode to Joy as the program executes.
- The Frog Eater is a two-motor controlled car. A third motor controls an arm, and uses ears to lift a hook that grabs frogs.
- The Dancing Turkey is a simulation of a turkey dancing with a robot. Two two-wheeled platforms each have a motor attached to a wheel. The other wheel moves freely. Moving randomly, the two platforms are connected by an arm with three joints, creating a breakdancing turkey and robot.
- Musica: The Drummer has two arms connected directly to motors that beat a raised Lego drum. The arms are programmed to move up and down in alternation.
- Christmas Tree is a robotic Christmas tree that features light-up and spinning-pulley ornaments. The lights blink on and off as the RCX plays Christmas carols.
- The Creature is a robotic car with an elaborate Pokemon mask.
- The Art Mobile uses gears to lower many crayons and draw on a piece of paper randomly. The group had trouble getting enough tension on the crayons to have them leave marks as the robot was driving.

Child Only Group 1

- The Speeder is a car that drives around and has a long arm that allows it to make bubbles if it comes across a bucket of water.
- The Music Box is a Lego structure that houses the RCX. When a button is pressed it plays a song as a motor on top spins around.
- The Roller Coaster is a giant platform that is programmed to go up and down, while surrounded by a jungle aesthetic.
- The Kicker is a soccer simulation. A boot is attached to an arm on a motor. It is aimed at a goalie that moves back and forth along pulleys attached to motor.
- The Windsurfer is a fan attached to a tower of Legos. The fan is attached to a motor.
- The Dragster is a long, skinny car that was repeatedly rebuilt after crashing into walls. It was refined to survive high-speed impacts. It uses two large wheels attached to two individual motors.

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- The Digger is a mole that digs at the press of a button. Two axles are attached to two motors, which in turn have arms on them. When the button is pressed, the robot starts digging.
- The Windmill is a fan attached to a tower. The motors spin a work gear, which then turns the gear attached to the blades of the windmill.
- The house has a door, which is attached to a motor. When a button is pressed on the door, it opens.
- The Giraffe is a tall structure with four long, skinny legs. On these legs rests a platform, where a Lego man rides the giraffe. A motor spins the head and neck around in circles.

Child Only Group 2
- The Crazy Nutcracker uses a gear system to open and close its mouth while two eyes light up. The motor is programmed to oscillate back and forth.
- The Amusement Park uses motors that spin axles that have nets at the end to create rides. The building makes heavy use of color and structure to create the large amusement park.
- The Egg Beater Ferris Wheel is a huge tower with a motor attached to a wheel at the top. two axles protrude to connect to an even large beam structure. At the ends, axles connect to chairs that are always oriented in the right way as the Ferris wheel spins.
- The Crazy Basketball Field is a lever attached to a motor. The arm is of the length such that when the motor is fired, an object is slammed into a basket.
- The Hockey Fan is a fan attached directly to a motor that sits over a Lego ice skating rink.
- The Menorah consists of nine lights and three touch sensors. The first light sensor is positioned over the Shamus, and shining a light at it causes the Shamus light to glow. The second light sensor is at the far right, and when activated the right side of the Menorah glows. When the left side sensor is shown light, the Left side glows, and the menorah begins to spin through a motor positioned at the bottom and sings dreidel-dreidel as it goes.
- The Garden a car controlled by two motors in the rear. In the front, a Lego garden sits upon a plate suspended in the air by four wheels and carefully balanced so as not to fall off.
- Three children built cars, but all utilized different designs. One uses motors attached to pulleys, as this allowed the motors to by placed away from the wheels, something that the child felt added strength to the structure of the car. Another was build to look like a dragster, and was programmed to move forward and then back. Another car also explored the idea of designing a stable

In reviewing this list of projects, it cannot be understated that every single project used some form of programming. The children all used the ROBOLAB programming language and developed software for their creations. As we can see, this software all follows a certain pattern—the robot executes code, waits for a stimulus, usually the passage of time, and then executes different code to alter it's actions.

Discussion

The final projects give a chance for children to show off the knowledge they have acquired during the five-week session, and perhaps put together some more. Selected stories help illustrate a child's thought process and allow us to think more about what was happening in some particularly successful instances.

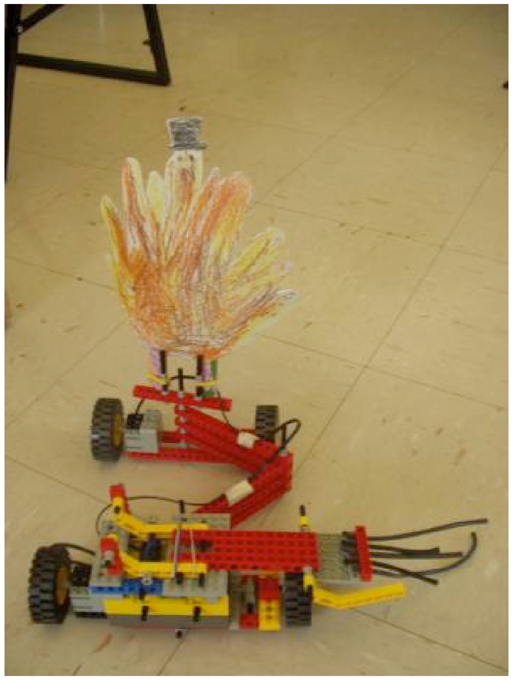
The Nutcracker allowed one young girl the chance to work closely with one of her teachers in a one on one setting. Celia knew she needed to get the mouth to open and close, but couldn't figure out how. Her teacher reminded her that before they had spoken about gears, and that when they meshed together they had some special properties. Celia then recalled that gears move in opposite directions, just like she would need the jaws of her Nutcracker to do.

Celia and her Nutcracker

She then attached the jaws to two axles that would move independently of one another. She built a structure that could hold the two axles, and when they rotated, the jaws could open and close. She attached a motor to the lower gear, and programmed it to oscillate, leading to jaws that opened and closed.

Her teacher took advantage of an engineering tool, but the application differed from the traditional application. Though children are often shown that gears rotate in different directions, the main thrust is with the ability gears have to change power and speed. In this case, those properties weren't useful to Celia. This was not an uncommon occurrence throughout the course of the workshop.

The Turkey-Dancing Robot was one of the most unique projects built for the workshop. In a manner of extreme silliness, a robot sculpted of Legos dances with a turkey cut out of cardboard and colored in – capped in a top hat, of course. In order to achieve Rebecca's vision, she and her dad cam up with a novel approach to using axles in the machine.



The Turkey-Dancing Robot

Two independent platforms support the turkey and the robot, but they are connected by an arm with three joints. At each of these joints sits an axle, which allows it to rotate nearly 360 degrees. This allows for the robot to appear to dance as the motors move randomly.

In both the case of the Nutcracker and the Turkey-Dancer, we see a teacher working intimately to solve an engineering problem with solutions that have very concrete benefits to a child's education. Simple machines are part of the Massachusetts State Engineering Frameworks – the child will see these explorations of gears and axles again. However, they're drawing their power because they're connecting on a level that is important to a child. We don't see axles being important to Rebecca because they allow for wheels to turn, they're important for her because they allow for her robot to dance.

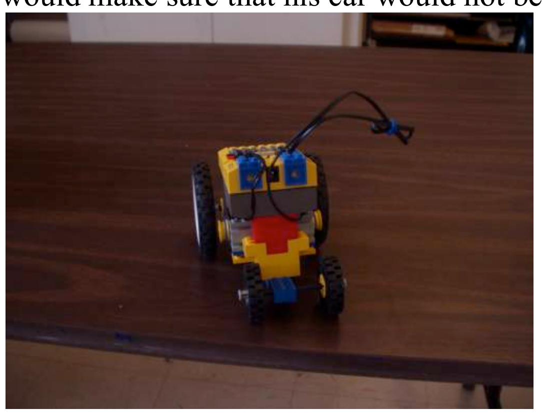
The Turkey-Dancer illustrates something else more sublime, Rebecca's penchant for silliness. To watch her giggle as her robot convulses across the floor is to understand her motivation in engineering. Rebecca learned that engineering can be a mean to itself. She can control what engineering does for her, which is an important distinction to make. Rather than focus on the litany of objects that engineering has already provided for the world, she gets to pursue knowledge on a level important to her, her own enjoyment. In engaging her at this level, she becomes captivated in the project.

We see aesthetic explorations over and over. Many of the more simple endeavors are truly beautiful in their own way: an Amusement Park only has two motors to spin, but the entire structure is very rich and textured. A Vit-Vit represents a mystical Japanese fairy, and although it's simply a car, it's built over a colorful, hand painted paper mache mask.

An Amusement Park and the Vit-Vit

We did not try to teach the children in order to guide them in a certain direction or take a certain view of engineering, and the result is that they believe that engineering can be a method of expressing themselves.

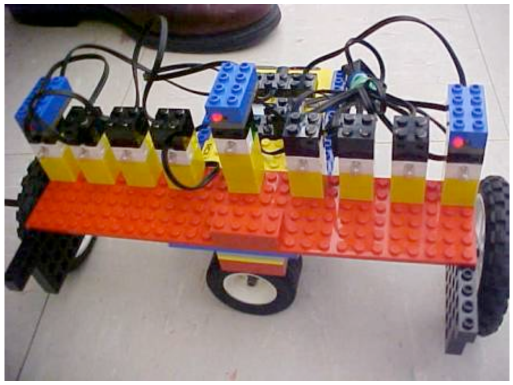
Under these circumstances, we see a great deal of learning happening when the students explore their ideas with a teacher. Sasha worked diligently on a car, a project that in scope seems more limited than the other. However, Sasha spent a lot of time with his instructor talking about structure and how he would make sure that his car would not be fragile.



Sahsa's Car

Inadvertently, Sasha was lead into a discussion on the design process, and he remarks about how frustrating it is when his car breaks. However, every time, he rebuilds and makes it better. At the end of the workshop, Sasha's head teacher became very impressed with the knowledge he had developed.

We were also very successful teaching computer programming, as all of the projects utilized a computer program of some sort. As these computer programmers were written in the ROBOLAB language, they utilized the structure of the language, children would build a program that executed an amount of code until a stimulus was achieved, and then execute another piece of code. Usually, the stimulus was an amount of time passing. Michela's menorah was one of the most sophisticated versions of this.


Michela's Menorah

She managed to program a device that waited for three separate stimuli, although they needed to be entered in the correct order. She worked closely with one of her teachers to achieve this, but in the end provided almost all the code by herself. In the process, she, like the other children, became comfortable with the language of ROBOLAB, catering to its need for wires and finicky connections between icons.

The creativity and imagination expressed by the children is striking. All of these projects, even when children worked with parents, were brought forth from the child's mind, although, especially in the parent-child groups, the interactions with adults seem to breathe life into the child's mental representations.

Future Research

The linear nature of Michela's, and indeed, all other robots probably suggests a developmental process at work. This is somewhat reminiscent of the long cherished concept of conservation[6]; children in this case are only looking at an immediate straightforward view of the programming language. Executing code in parallel doesn't occur to them. ROBOLAB provides structures where we can more closely examine these tendencies, by offering structures such as loops and forks, we can see what structures children gravitate to, and if they're able to rationalize these ways of representing code. Traveling down this path leads to representing engineering development in the same language as classical development, enabling greater insights in both. The programming observations also have implications for teaching that we should explore. The concept of 'waiting,' which is the vocabulary used in ROBOLAB could be all too familiar with children, and the structure of the programming language could be exploiting this. If so, then this becomes a useful pedagogical agent for teaching the programming language.

We also strive to clarify the link between aesthetics, play, and engineering. Further research could illuminate the value of having projects with functional value only apparent to children. This requires a non-traditional view of engineering materials, as children will readily subvert ideas such as simple machines to their own ends. Before fully embracing such a track, however, we must be sure that the knowledge they obtain is useful and long lasting.

Finally, a note on methods in projects such as this. Although we collected video data, we ultimately found it hard to disseminate. Because of the size of the group the photographer could rarely follow interesting conversations as they unfolded, leaving us with teacher and student recollections and narratives. More careful attention to video data would allow more rigorous study of the results.

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