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Lego Robotics in Elementary Education

An Interactive Qualifying Project
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WORCESTER POLYTECHNIC INSTITUTE
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by

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Abstract

Constructivism, and constructionism, in their purest form, evoke the idea of learning-by-making and structuring a curriculum so as to encourage innovation, and therefore, enhance both the desire to learn and the desire to teach. This project demonstrates the utmost importance of adaptive teaching in progressive education. Using LEGO Mindstorms, constructionism is fully realized. A Mindstorms curriculum based on the theories of progressive education, which bears in mind the various learning styles, encourages self-discovery in both students and teachers.

Patrick Spencer

Acknowledgements

The author is indebted to Worcester Polytechnic Institute, The Bancroft School, and the Elm Park Community School for their belief in, and willing participation and involvement with LEGO Mindstorms. More particularly, this project would have been no more than a fleeting thought was it not for Professor Art Heinricher and his wife, Elisa's passionate dedication of bringing science and technology to elementary students. Equally as crucial to the success of the progressive program that the author developed was Mr. Chalie Aleksiewicz, director of Special Programs at Bancroft. His boundless love for children and education was inspiring. This paper would have been without structure were it not for the guidance of Martha Cyr. Her experience with working with and teaching both students and teachers was invaluable in helping me establish goals for my classroom activities.

Lastly, and most importantly, the classes would not have been a success were it not for the tireless work of all my assistants. With that in mind, this paper is humbly presented in honor of Sean Waithe, Alex Heinricher, Nick Alunni, Dan Reilly and Keithe Baggett. My endless thanks and applause for your professionalism and patience.

"May we never rest until every connector peg, plate, beam, brick, and angle beam is sorted."

Patrick Spencer

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1. PURPOSE

This paper is part of a larger initiative being developed by Worcester Polytechnic Institute, Bancroft School, and local public and private schools.

The Bancroft School in Worcester, Massachusetts, in the last few years, has made an effort to enrich student's educational experience through a host of extracurricular activities. Mr. Charles Aleksiewicz, Director of Special Programs at the school, designs and offers these hands-on opportunities in order to expand the creativity and awareness of motivated students. Mr. Aleksiewicz works to ensure that all course philosophies are centered around the age-old adage that "learning should be fun."

The Bancroft School's diversity of educational topics makes its sessions popular with both children and adults. The Bancroft School offers courses such as: Kitchen Chemistry, LEGO Robotics, Study Skills, Phonics I or II, Math Mania, Learn to Draw, Webpage Creation, Fun with Literature, Multi-Media, Keyboarding, Clay Creations, Cooking, Sign Language, Weather Forecasting and Woodworking. Either WPI professors or students have taught the LEGO Robotics course for the last seven years.

Introducing engineering undergraduate students to Robotics allowed WPI undergraduates to participate in activities that would marry technology with specific societal needs. Curriculum development, in guided by thoughtful educational philosophies, was an appropriate means of marrying technology, in this case LEGO robots, with societal needs. The prevalence of what John A. Dewey would describe as *traditional education*, and Seymour Papert called *instructionist learning*, led to an examination of possible alternative educational philosophies. The societal need to be addressed was the development of a curriculum that lends itself to the hands-on nature to LEGO Robotics. The curriculum, based around physical science terms called *original ideas* was intended to assist students to communicate better in light of the various learning styles.

This paper and the curriculum described herein, strongly support Papert's theory that developmentalism, and in particular, constructivism and constructionism, enrich learning for students, while also enriching the teaching experience for teachers. Contrary to the belief of J.E. Stone[1] that developmentalism is a crippling restriction on schools in their attempt to hold students accountable, this paper demonstrates standards which are integrated into a hands-on curriculum provide clearer goals for students to achieve.

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[1] J.E. Stone, "Developmentalism: An Obscure but Pervasive Restriction on Educational Improvement," *Education Policy Analysis Archives* 4, no. 8 (1996)

2. **INTRODUCTION**

There is no doubt that Americans are in the midst of a technological revolution. The United States Census Bureau reported in September of 2001 that at least one computer was present in 51 percent of households (54 million) in America in August of 2000. This number is staggering when considering the fact that in December 1998, only 41 percent of households had a personal computer, and only 8.2 percent in 1984. Similarly, in the year 2000, 41.5 percent of households had access to the Internet, compared with only 18 percent in 1997 and a negligible percentage prior to 1993. Computers have revolutionized the way that Americans accessed information. The Internet, often referred to as the information super highway, is rapidly gaining acceptance as a credible, and quick-responding, source of information. Children have the greatest chance to benefit from this rapidly growing advancement.

Children are immersed in computer-aided environments at both home and at school. Among school-aged children (6 to 17 years), two in three had access to computers at home. Similarly, 57 percent of children had computer access at both home and school. In total, roughly eight out of ten students have access to a computer at school. While computer access at home differs among various income, race, or ethnic groups, statistics show that school leveled the playing field by giving computer access to children who have none at home. Of school-age children in the highest income bracket, 94 percent had computer access at home. Those with incomes less than $25,000 had access to a computer at home only 35 percent of the time. But at school, 87 percent of the highest income group had computer access, while 72 percent of the lowest income students did as well. Between school and home, school-aged students have ample opportunities to use computers. Only 10.4 percent of school-aged children do not have access to computers, and with computer prices continuing to drop, this number will undoubtedly shrink[2].

Children's immersion into the computer-savvy world makes it plausible that computer-aided learning will enhance their development. Among both children and adults, the most common use of the Internet was for E-Mail. Adults used the Internet far less for any other task, with the next being information searches such as news, weather reports and sport's scores. Students, however, used the Internet equally as often for school research or course work as they did for E-Mail: 20.7 percent to 22.2 percent. The computer and the Internet are becoming common tools for students' schoolwork. Educators must realize both the student's purpose for using the computer and Internet and the methodologies employed by students if they are to teach effectively.

The relatively recent emergence of computers as teaching aids can cause friction between the teacher's existing methodology and the children's evolving abilities. Some activities, which can be completed using more standard means of learning, are not seen by students as easier to complete using the computer and Internet.

> *We'd all have to go into the library and use the Internet. Like, it would be so much simpler to use an encyclopedia or book. I mean that sometimes teachers just want you to use the Internet because it's the Internet – let's integrate it into*

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[2] Eric C. Newburger. "Home Computers and Internet Use in the United States: August 2000,"

schools…Sometimes teachers just don't know…when it's easier to read a book and when it's easier to use the Internet.

- High School girl[3]

A common problem of using the computer for educational purposes is that assignments that do not engage the students in active learning are construed as boring or a waste of their time; as Papert says, "the presence of computers begins to go beyond first impact when it alters the nature of unchanged school." This point is demonstrated below.

In English class last year we were supposed to be working on a Web page, but we got bored and downloaded music.

- High School girl[3]

A lack of interactivity and understanding caused this student to become distracted. She could not see the value in developing a Web page for an English class. The presence of computers did not go far enough to engage the students, but rather was just a different route to the same (old) result.

Engaging students to actively interact with activities can make self-discovery plausible, and encourage continuity in both learning and teaching. According to Papert, computers figure so prominently in engaging students because of the wide range of contexts with which they can be used.

For chemistry, we actually go to these sites. Some of them are actually helpful. There are interactive movies that explained things. It was really a good way to study.

- High School boy[3]

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[3] All direct quotes from students were taken directly from Levin's *The Digital Disconnect* for the Pew Internet and American Life Project

The student was able to connect what the movies were describing with the material that was being presented in class. By interacting with the computer, he developed a tangible sense of how these theoretical lessons were real.

> *In Science, we had to do this project on volcanoes. [Our teacher] said maybe you should go to the Internet to find out and see if there's more things you can learn about volcanoes…When I went on the Internet and it had more things like why the volcano will explode and the types of gases inside of it…or if there are any close to cities around the world – that kind of stuff. So, it made it easier to understand it and I got a good grade on my assignment.*
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> \- Middle School boy[3]

In trying to reach a point of equilibrium, whether it is about the explosion of volcanoes or how to produce table salt through various combinations of elements, if the student is given the correct tools and encouragement, the instructional learning process can adapt, and be itself a constructive tool for discovery.

Constructionism, in its simplest form, evokes the idea of learning-by-making and structuring a curriculum so as to encourage innovation, and therefore, enhance both the desire to learn and the desire to teach. Influenced by the constructivist philosophy of Piaget, and sharing in its connotation of learning as "building knowledge structures," constructionism, according to Papert, is a radically better teaching method than the "instructionist" modes prevalent throughout school systems presently. By encouraging creativity, especially in traditionally uncreative topic such as math and science, the result will be an insatiable desire to continually shape his or her mathematical or scientific "sculpture." LEGO Mindstorms, and the projects that they inspire, lend themselves to the objectives of constructionism.

Using LEGO Mindstorms in the classroom encourages students to build knowledge structures by building robots. The curriculum developed by the author of this paper had two foci: to expose the children to *original ideas* through the construction, programming and operation of LEGO robots, and expose the students' varied learning styles and then to adapt teaching methods to these styles. The learning styles used here are adopted from the United Kingdom's Department for Education and Skills. The original ideas presented to the students are relatively advanced physical science topics. Furthermore, this project is intended to demonstrate that computers and technologically-advanced tools, when used correctly by both teachers and students, can encourage learning through self-discovery. Persons young and old peruse the Internet, searching for various topics. However, software such as Robolab can encourage the same type of enthusiasm and curiosity for learning. A teacher who understands the varied learning styles of the students and the standards of achievement will play a vital role in a child's development. In this environment, learning will be fostered by both the teachers and the fellow students.

3. THEORETICAL BACKGROUND

Progressive learners believe instructional learning, and its pattern of organization, is a sharp contrast to almost every other social institution that exists. Students learn primarily from texts with guidance from teachers, and ideas and concepts therein are absorbed through homework and testing. Promotion and rules of order built on generic testing are prevalent. Call to mind school's pattern of testing; requiring shear memorization of abstract facts and asked in various formats, none of which foster more continuity of subject. Schemes of organization, that is, grouping students by their "intelligence level," exists almost nowhere else in democratic societies[4]. Traditional education and its methods of instruction and testing are not conducive to deep learning. The various patterns of organization and empirically demonstrated merit, while well intended, inhibit developmental growth and interest. In contrast, developmental construction of knowledge in children is a philosophy that consistently assesses the organization of a child's mental structures, and works to build upon things familiar to them.

Developmentalists seek to change childrens' coherent and unique views of the world through filtered methods, rather than content, which provide various contexts that may shift the views held. The origins of developmentalism, as conveyed by Rousseau (1712-1778) held the "natural" course of development in children as optimal, and that any societal intervention would spoil native tendencies and characteristics. Less naïve educational philosophers such as Dewey, Piaget, and later, Papert, held the idea that

[4] This is one of the main themes in John A. Dewey's work.

children's views can be enhanced through filtered experiences. The educational values to these experiences are measured by their continuity to both past and future experiences and the level of interaction "wherein the native characteristics selected-for by evolution were enhanced by the naturally occurring experiences to which they were fitted."[5] This is not to say that instruction is rendered useless. On the contrary, according to Papert, "children might want to learn it [construction kits] because they would use it in building these models...Moreover, since one of the reasons for poor teaching is that teachers do not enjoy teaching reluctant children, it is not implausible that teaching would become better as well as becoming less necessary."[6] Developmentalists believe in a theory of idea power. Experiences, which enrich student's development and cause further investigation, are considered prime causes for learning. The developmentalists take various approaches to enriching student's views, yet their methods are all guided toward the same end.

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[5] J.E. Stone, "Developmentalism: An Obscure but Pervasive Restriction on Educational Improvement," *Education Policy Analysis Archives* 4, no. 8 (1996): 6

[6] Seymore Papert and Idit Harel, "Situating Constructionism," in *Constructionism* (Exeter: Ablex Publishing Corp., 1991), 5

3.1. JOHN DEWEY AND PROGRESSIVE EDUCATION

Progressive education allows the students to invest their time in exploration and self-discovery. The progressive schools came to be because of frustration of its forward-thinking constituents with the mainstream methods of education. A student's inner-self was the main concern of these progressive schools. There is a purposeful lack of organization. The educational reactionaries who created these schools failed to create a set of empirical or statutory guidelines. Dewey believed that a serious problem in progressive schools was a lack of discipline. The educational philosophy was oversimplified in application.

Progressive educators believed that it was natural for a child to *discover* new ideas, actions, etc. They thought that any screening of experiences was unnatural and would hamper the child's growth.[7] Dewey, however, believed that a student's education benefited from a modified structure.

There are two dimensions to any experiences that students can have. An experience can be weighed for its effect on further experiences. An educational experience has the potential to yield positive results educationally and may lead the student to desire more similar experiences. The second aspect of experience is its agreeableness with other experiences.[8] Does the experience, or at least the idea behind it, resemble other experiences? In other words, is there any level of consistency or connection with previous experiences? Valuable educational experiences enlighten a

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[7] John Dewey, "Traditional vs. Progressive Education," in *Ecperience and Education* (New York: Touchstone 1938) 21
[8] Ibid.

student and cause them to seek similar experiences in the future. Anyone who has ever built a model, or attempted to piece together a puzzle knows the excitement that comes with a sense of accomplishment. That excitement is the best motivational tool to continue working. Education based on experience needs to be selective in that it must choose those experiences that will be most appropriate for the student, and produce the most positive return.

The criteria upon which experiences are judged are rooted in Dewey's *experiential continuum*. The theory discriminates between worthwhile educational experiences and those which have no pedagogical value. The continuum has two pillars upon which it is developed. First, Dewey believes that a democratic social environment promotes a better quality of human experience. Secondly, Dewey believes that every experience modifies future experiences. It is the quality of the experiences that affect the way the principle applies. Dewey states, "…the educative process can be identified with growth when that is understood in terms of the active participle, growing."[9] Dewey's theory of continuity believes that no experience exists in and of itself. The theory of continuity lends credence to the belief that children learn from their experiences, and that this process is natural.[10] While Dewey's theory of continuity focuses on a person's internalization of experiences, his theory of interaction brings to fruition the relationship between situations and the experiences they create.

A person interacts with his environment by influencing situations and being personally affected as a result. There is a certain dichotomy to interaction; that is to say, there are external as well as internal factors. The external factors are what a person says

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[9] Ibid., 36
[10] Ibid., 38

or does, and the types of responses that he receives. Internal factors, which Dewey believed were largely ignored by traditional educators, are concerned with how the person is affected by the responses he receives. "Any normal experience is an interplay of these two sets of conditions. Taken together or in their form of interaction, they form what we call a *situation*."[11] Dewey's theory of interaction believes that each situation provides a new experience. A person will rarely say the same thing twice, and even more rarely receive the exact same response. Therefore, it can be deduced that no two experiences are ever alike. This explains his theory of continuity. Were each experience to exist alone, without regard for past experiences, a person would never learn from a situation. Dewey's belief that all situations are unique explains how we weigh the value of the experiences that we face.

The theories of continuity and interaction provide a tool for measuring the educational significance of all experiences. Together they make up the breadth of all experiences. People are consistently interacting with each other. There is a sense of continuity to these experiences. Every situation that a person meets tends to be the result of some previous experience. "As an individual passes from one situation to another, his world, his environment, expands or contracts."[12] A person is more prepared, more capable because he has learned something. That lesson will be applied to all future experiences. The role of the educator is to use Dewey's principles and select the most appropriate experiences.

[11] Ibid., 42
[12] Ibid., 44

3.2. JEAN PIAGET, CONSTRUCTIVISM AND COGNITIVE DEVELOPMENT

Jean Piaget's educational philosophy is built upon the belief that children develop logical and coherent views that most suit their current plan or framework and demonstrate their possibilities in assimilating items in their current environment; that is, they learn by doing. When they are very young, a child's, "intelligence progresses from a state in which accommodation to the environment is undifferentiated from the assimilation of things to the subject's schemata to a state in which the accommodation of multiple schemata is distinguished from their respective and reciprocal assimilation."[13] Assimilation is the process of using or transforming the environment so that it can be placed in preexisting cognitive structures. Accommodation is the process of changing cognitive structures in order to accept something from an environment.[14] If assimilation were a person, they would want the world to change for them. If accommodation were a person, they would change for the world. In other words, the development of intelligence in children begins in an environment that, by its nature, supplies or satisfies a need. In this environment, various different things absorbed by the child are seen as the same. When a child learns to talk, he does not immediately understand where one word begins, and another ends. According the Piaget, children's intelligence will mature to a state in which the respective, and sometimes opposite, values of different plans or schemes will become evident. Also, the different environments that these plans will be presented in

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[13] Jean Piaget, "The Elaboration of the Universe," in *The Construction of Reality in the Child* (London: Routledge and Kegan Paul, 1955) 1
[14] Huitt and Hummel, "Piaget's Theory of Cognitive Development," *Educational Psychology Interactive* 2003: 1-3

will be distinguishable to the child. By age one, a child begins to acquire object permanence, and symbolic abilities. This is when words such as "good" or "bad" begin to be understood.

As knowledge of various topics is accommodated, they will begin to assimilate further information differently. To Piaget, "assimilation and accommodation proceed from a state of chaotic undifferentiation to a state of differentiation with correlative coordination."[15] That is to say, while at first information which a child is supplied in order to satisfy a need cannot, at first, be distinguished from the absorption of all information. A child, with the passage of time, will construct a practical view by combining information that satisfies a need with the absorption of objects so as to harmonize a differentiation that exists in their mind.[16] The construction and reconstruction of the child's reality is accomplished through this method.

Piaget's theory of cognitive development, like its parent, the cognitive system, relies on the importance of feedback. Cognitive development studies the processes and stages of a child's engagement with symbolic, abstract thoughts, and how their engagement has an effect on their environment.[17] Piaget's levels of cognitive development are as follows.

1. Sensorimotor Period – birth to 2 years
2. Preoperational Thought – 2 to 6 years or toddler to early childhood
3. Concrete Operational Period – 6 years to 12 years or elementary to early adolescence

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[15] Ibid., 3
[16] Piaget, *The Construction of Reality in the Child*, 1-5
[17] Huitt, "The Cognitive System," *Educational Psychology Interactive* 2004: 1

4. Formal Operational Period – 12 years to adult

The six-stage sensorimotor period is based on physical interactions and experiences using eyes, ears, hands, and other sensorimotor objects. What initially can only be considered reflexes quickly develops into a level of permanence as the child becomes able to remember sophisticated procedures. By age two, symbolic language skills are developed. Movement to the preoperational stage means that symbols for language and mental imagery are developed. For instance, the color orange becomes associated with a carrot. Thought does not necessarily have logic, images are irreversible and activities are often generalized. During concrete operations, logic is further developed, yet abstract problems are still unsolvable. Multiple perspectives can be considered simultaneously. Symbols such as language can be manipulated, and egocentric thoughts diminish. When children can solve abstract problems and relate the logical use of symbols to abstract problems, they can be considered to be in concrete operations. Piaget's cognitive development is demonstrated in the form of the application of consequences from the environment.[18]

Piaget's theory supposes that children interpret all their experiences, which are acquired through interaction with external factors. "Piaget's constructivism offers a window into what children are interested in, and able to achieve, at different stages of their development. Conceptual changes in children, like theory changes in scientists, emerge as a result of people's action-in-the-world, or experience, in conjunction with a host of 'hidden' processes at play to equilibrate, or viably compensate, for surface

[18] Ibid.

perturbations."[19] Children are content with their current views, and until adolescence, their logic is often irreversible. Therefore, the standard delivery methods of knowledge will not affect their views. They will dismiss theories that do not match what they already think. Qualitative and quantitative studies demonstrate that only between 30 to 35 percent of adults attain the formal operational cognitive stage. Conceptual and idea changes in children require that their egocentric views are disassembled and activities that encompass a wider range of situations, including views previously held, are demonstrated. Piaget believes that equilibrium of assimilation and accommodation will allow for cognitive change. Papert's theory provides context, uses, and media as vehicles by which the student will be able to balance the information they are receiving with schemes they have already formed.

3.3. PAPERT AND CONSTRUCTIONISM: PEDAGOGY OF IDEA POWER

Seymour Papert's philosophy of learning is a study of genetic epistemology that reaches beyond the "discovery learning" that Piaget implies in his work. In his book *Mindstorms*[20], Papert adds a dimension to Piaget's cognitive development which he called a *transitional object*. The original transitional object, a differential gear that captured his fascination as a child, was constructed in his head as both a sensory and abstract item. "As well as connecting with the formal knowledge of mathematics, it also connects with the 'body knowledge,' the sensorimotor schemata of a child. You can

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[19] Edith Ackermann, "Piaget's Constructivism, Papert's Constructionism: What's the difference?" 2002, Massachusetts Institute of Technology Media Labs, 3

[20] Papert's book provided the motivation, as well as the name, for the LEGO Mindstorms line or products.

imagine yourself *being* the gear; you can understand how it turns by projecting yourself into its place and turning with it."[21] Papert's use of the transitional object demonstrates his concern for the vehicles of communication with children. Whether it is gears, or a computer, his work ensures that the object of manipulation is studied as much as the child. Papert's contributions to the field of developmentalism include the construction of items, and in turn, the building of knowledge structures.

Constructivists who believe ideas are better understood and learned by self-discovery of skills and facts are ignoring the importance of external supports, according to Papert.[22] Using constructivism, ideas such as manipulating fractions, which are already understood (hopefully) by those teaching them, are taught by creating environments that will most likely lead the student to discovery. In an analogous sense, it is a bit like drawing by connecting the dots, rather than beginning from scratch. The power behind the idea is lessened because it is not a genuine discovery. According to Papert, "it is disempowered in part because discovery stops being discovery when it is orchestrated to happen on the preset agenda of a curriculum but also in large part because the ideas being learned are disempowered."[23] What Papert promotes are intellectual tools that empower both the pedagogy behind an idea and the skills and facts associated with the idea. Papert's constructionism is rooted in the hope that innovations are able to produce radical change in how children learn.[24]

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[21] Seymour Paper, foreword to *Mindstorms* (New York: Basic Books, Inc., Publishers, 1980): VIII
[22] Ackerman, *Piaget's Constructivism, Papert's Constructionism: What's the difference?*, 5
[23] Seymour Papert, "What's the big idea? Toward a pedagogy of idea power," *IBM Systems Journal* 39, nos. 3 and 4 (2000): 722
[24] Papert and Harel, *Constructionism*, 4

Papert believes that "...knowledge should emphasize learners' conversation with their own favorite representations, artifacts, or objects-to-think with."[25] He believes that children will actually want to learn skills and facts if they have a model of an idea that they can manipulate. Students are continually adapting their models as they construct them, shaping and re-shaping them to fit some pre-established plan. Some students' models will closely resemble physical objects, while "others use abstract and formal means to distance themselves from concrete material."[26] The empowering of pedagogical ideas, while dissociated with constructivist learning, and in turn the emergence of encouraging further discovery, is orchestrated through modeling the idea according to their worldview. Encouraging this will lead to an immersion in the subject matter that is, according the Papert, similar to learning a foreign language by living in the country in which it is spoken, rather than sitting in an American classroom.[27] Papert's emphasis on appropriately manipulateable models as expressions of acquired skills and facts is demonstrated in carefully organized LEGO Mindstorms activities.

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[25] Ackermann, *Piaget's Constructivism, Papert's Constructionism: What's the difference?*, page 4

[26] Papert and Harel, *Constructionism*, 4

[27] Papert, *Mindstorms*, 6

3.4. LEARNING STYLES

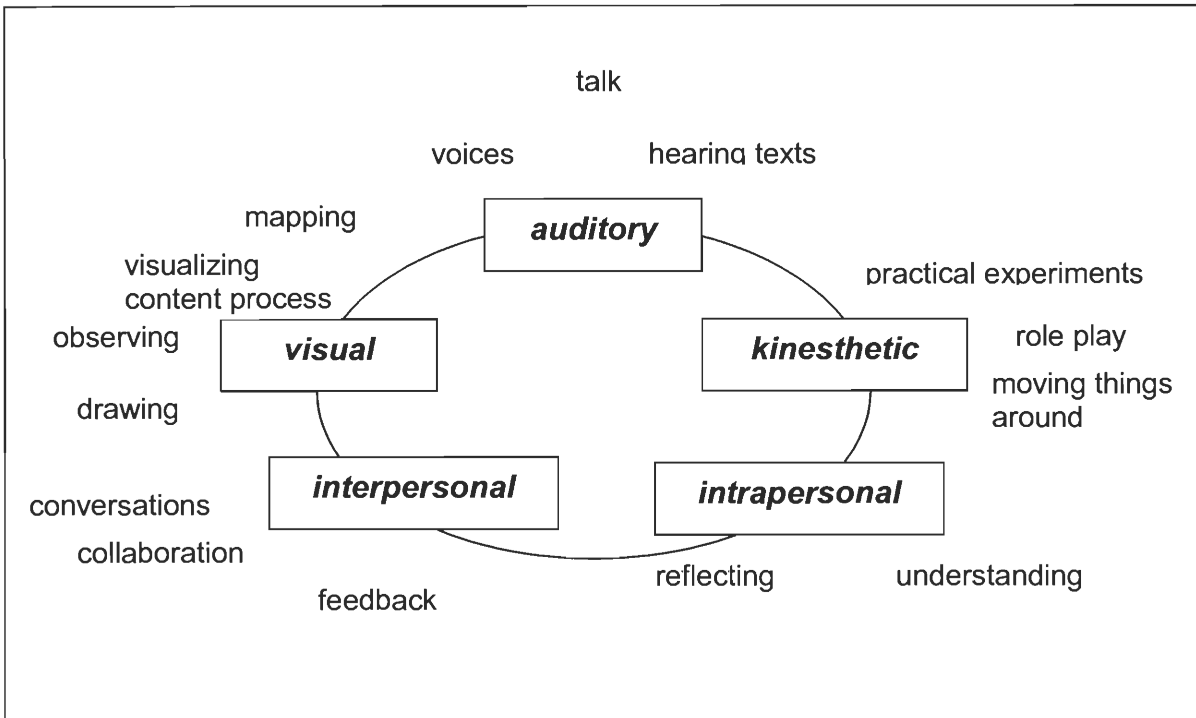

Figure 1. Learning styles in design and technology. Adapted from UK Standards

Not all people learn the same way. Take the example of building a kitchen table. The goal is to not have to eat meals at the kitchen counter or on the couch. The means of attaining that goal is in building a kitchen table. A person will purchase the components of the table and assemble it. Included with the components are instructions for completion. Some people look at the pictures that accompany the directions, while others will read the directions that accompany the pictures (sometimes twice). There are those who would have someone else read the instructions, while still others will throw the instructions away and try and build the table by putting the pieces together using their knowledge of how completed tables look. They can look at the components, identify the tabletop and know, from sitting at tables for their entire lives, where the legs should go.

Some people will also ask others to help them build the table. However it is built, the end result is a table with four legs, which hopefully doesn't wobble. The goal of being able to eat dinner not at the kitchen counter or on a couch has been met. Take five people, and while they may all end up with the same result they could have completed the project five different ways.

The five learning styles and the accompanying processes they envelope are important to consider during curriculum development. Figure 1 illustrates the five styles and the processes normally undertaken by students who learn this way. The most common learning styles: *visual, auditory, and kinesthetic*, make up the acronym VAK. VAK are the most common ways that students develop mental images for the first time. However, with increased frequency, students are using reflection and collaboration as a means of understanding concepts and ideas more fully. New concepts and ideas can be understood by students if they can relate these new ideas with ones that they already have. These students learn through interpersonal and intrapersonal processes. A curriculum that has the flexibility to be able to teach concepts through more than one of these processes will be successful. The environment that is created by LEGO Mindstorms should incorporate, in one way or another, all the learning processes. LEGO has gone to great lengths to ensure that visual learners have the tools necessary to complete the robots that they have designed. Teachers, therefore, must be ready to provide an environment that facilitates the other learning styles.

Visual learners can easily create mental structures from words or pictures that represent ideas. Visual learners are capable of viewing the content, layout, length, and process of writing and adapt the information to fit their ideas. Students develop mental pictures in either a single frame or in a series of sequential frames, much like a picture book. These images are translated into a language that inspires dialogue within the learner. There are many ways that students visualize images and interpret these images. They may create a drawing of what they are reading, or create a concept map. That is to say that the ideas that words or pictures are intended to convey can be realized through sketched images or word assimilations.

Concept mapping is a process by which a central idea is considered, and a web of related topics and ideas realized through exploratory thought are mapped on a piece of paper[28]. Tony Buzan refers to this process at mind mapping. "Rather than working from the top and working down in sentences or lists, one should start from the centre or main idea and branch out as dictated by the individual ideas and general form or the central theme."[29] These mind maps are not a finished product, but an exploratory method of self-realization of ideas. Mind maps can be developed, and re-developed or re-organized as many times as is needed. Alternatively, students learn visually by visualizing an entire text, deciphering symbolic representations, such as plans and diagrams, images and videos, and through observational analysis, including spelling.

Teachers, other students, and each student themselves participates in teaching audibly. Teachers read to pupils from the very beginning of formal education through higher education. "Hearing texts read aloud helps pupils absorb the style and idiom of texts in a way silent reading may not. Information texts sound differently to narrative."[30]

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[28] Learning styles and writing in Design and Technology, Key Stage 3 National Strategy, United Kingdom Department for Education and Skills, 5
[29] Tony Buzan, "Noting," in *Use Both Sides Of Your Brain* (New York: E.P. Dutton, 1983): 91
[30] UK Standards, page 7

A student's peers will use words and phrases that the student will pick up naturally if they are reading to one another. They become familiar with the language of the lesson. Teaching through hearing texts is used by both students and teachers. To hear a text is much different from silently reading it. However, there are additional processes which will help present an idea that may be difficult, or impossible, to gather from a text.

Processes such as collaborative writing, role-playing, speaking writing, and writing frames can enhance learning though auditory processes. Students in pairs or in groups can do all these various processes. Oral drafting, often called thinking aloud, facilitates composition, as anyone who has ever spoken to themselves while writing will testify to. "Collaborative writing makes explicit the process of composition as students suggest, modify, confirm, justify, improve, and refine their ideas together."[31] Role-playing causes a person to have to act as a knowledgeable person in regards to an idea or concept. Often times the scenario is structured, and students are allowed to prepare lines or words. The result is often a script, regardless of how preliminary, that can be used in other processes, such as writing for visual learners. Speaking writing is a term meaning to speak as you write. During these exercises a student reads aloud as he or she is writing. The student will develop an interior monologue that most educated people have developed. Teachers' use of certain prompts in order to assist students in developing sentence structures. They may help them begin sentences or problems in order to help the students gain momentum in understanding an idea.[32]

Kinesthetic learning gives children a physical interpretation of ideas or concepts. Commonly referred to as hands-on learning, kinesthetic activities must be practical and

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[31] United Kingdom Standards, 7
[32] Idid., 8

well organized. Attributive blocks help develop math and organizational skills by having the student construct various shapes from a variety of oddly shaped pieces. Shadowboxes are used by teachers who wish to have a child demonstrate their understanding of a story or concept. Whenever science teachers require students to produce a three-dimensional model of a human cell, or a history teacher requires students to build a replica of King Arthur's sword, they are requiring students to move ideas in a physical sense and collaborate with others. This collaboration will require students to verbally and physically show how they view an idea and require them to gain input from others, be in their parents, fellow students, or a teacher. Students' physical interpretations can be assessed and will allow teachers to determine what aspects of a topic or idea are well understood and which need refining. Hands-on learning has many resources, including LEGO Mindstorms, that require monitoring and assessment by teachers; students must also be able to assess their work with their peers and on their own.

Interpersonal and interpersonal learning must be considered because so much of education relies on reflection and collaboration. Interpersonal learning is demonstrated by what has become known as group work. Students complete tasks in groups of either two or more from the beginning of early education through graduate school, in some instances.[33] Students are constantly receiving feedback on an idea that they present. Students who have positive attitude and are able receive and understand constructive criticism will be able to reflect on the ideas given to them by others. Those two

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[33] Personal experience. Worcester Polytechnic Institute prides itself on providing an interactive learning experience. Many courses require students to complete assignments as a team. Two of the most important exercises required for completion of an undergraduate education are independent projects that engage the students in real-world scenarios. These projects are intended to be completed in groups of two or more.

processes, understanding and reflecting, comprise intrapersonal learning, or gaining knowledge about oneself.[34]

The different learning styles should be considered as collaboration. Because someone learns best by building models, does not mean that they are ineffective in reading instructions. The most inept learners have developed the abilities to learn in multiple ways. Different ideas will lend themselves to one learning style over another. A student may understand arithmetic by verbally adding numbers, but need to read about the evolutionary history of a frog. Learning styles can be developed through repetition and structured exercises monitored by teachers who understand the goals and ideas themselves.

[34] United Kingdom Standards, 10

4. METHODOLOGY

4.1. THE LEGO INSTRUCTIONAL TEAM

The LEGO team consisted of seven individuals who each contributed to the team in their own unique ways. Each member had an area of expertise that, in keeping with the spirit of developmentalism, would encourage students to discover ideas and construct robots that matched their understanding. There was never an occasion during which all the team members were present. The various combinations of instructors made up a unique persona that inspired the students to discover ideas and use their imagination.

Prior to each class, the project leader met with the team and discussed the goals for the project. The leader would assign various tasks to the team, depending on their areas of expertise.

Art and Elisa Heinricher are the longest-serving team members. Art is a mathematics professor at WPI and Elisa is a computer systems specialist at The Bancroft School. They developed the original course curriculums based on their experience as educators and keeping in mind past projects that students enjoyed and did not. Professor Heinricher has a long history of integrating and bridging mathematics into initiatives such as high school curriculums and industrial mathematics. It was his diverse, yet seemingly seamless, integration of mathematics into various societal systems that prompted the writer of this paper to join the project.

The writer of this paper began working as an assistant with Professor Heinricher in the winter of 2003. The number of students required an assistant to monitor the children's progress and assist in construction. The writer of this paper quickly became enthralled with the students' ranges of abilities, and decided to further study this "hands-on" learning environment and its effects on child development. In order to better understand this "new" style of learning, the educational philosophies and techniques of various philosophers including Dewey, Papert, Piaget, Bruner and like-minded philosophers were studied. The concepts central to developmentalism became the building block around which the curriculum was redeveloped once the writer of this paper ran classes, starting in spring of 2004.

Four male assistants, Sean Waithe, Daniel Reilly, Alex Heinricher and Nick Alunni brought both their experience and collective energy to the project. The assistants, themselves only in high school, had all completed a semester-long robotics class at Bancroft School. They had intimate knowledge of the various LEGO components, and the ability to efficiently manipulate the software so as to elicit the desired responses from their robots. In having already built robots using LEGO Mindstorms kits, they were privy to knowing what conceptual topics would cause angst amongst the class, and which they would likely have ease in constructing. Sean also quickly became a favorite amongst the students for his no-nonsense attitude.

Keithe Baggett was the only other female team member. Each class just so happened to have a at least one female student. With the class predominantly male students and instructors, there was concern that the uniqueness of the girls' mental structures would become disenchanted and they would feel pressured to build in a similar fashion as the male students. Keithe's involvement gave the girls an instructor who they could most closely relate to. Her patience and compassion were largely effective with students who were otherwise uninterested in the project that they were supposed to be working on.

4.2. LEGO MINDSTORMS AND ROBOLAB

Seymour Papert is interested in the context in which children use objects to facilitate self-directed knowledge, and in turn, either mentally construct new bodies of knowledge or modify the knowledge they already possess.[35] *LEGO Mindstorms,* developed by MIT and the LEGO company, would eventually be the vehicle which would bring his philosophy to the classroom.

> "As the Logo language [Mindstorms ancestor] was developed, it came to have at least two characteristics that distinguished it from other contemporary computer programming environments. The first was its interactivity, which it shared with Lisp, the language on which Logo was based. The other feature of Logo projects was that they expanded the realm of the computer beyond data manipulation."[36]

Although Logo was built nearly thirty years prior to Mindstorms, the theoretical basis that started with Logo and was continued at the MIT LEGO/Logo lab with the development *LEGO Technic*, and *LEGO TC.* In 1998, LEGO Mindstorms became the latest generation of LEGO products developed with a constructionist classroom in mind. LEGO Mindstorms for School, the kit intended for schoolchildren ages 5 to 16, was utilized by the team at Bancroft. The program embraces Papert's constructionism, and on

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[35] Ackermann, *Piaget's Constructivism, Papert's Constructionism: What's the Difference?*, 1
[36] Fred G. Martin, introduction to *Robotics Explorations* (Upper Saddle Hill: Prentice Hall, 2001): 8

a larger scale, the thought that developmentalism allows for children to discover idea power, while providing ample unique opportunities for teaching. The Mindstorms for School kits versatility was considered their most important characteristic.

Children reconstruct ideas by comparing and contrasting their mental constructions with experts' constructions.[37] In describing a Mindstorms robot to children, the writer of this paper assumed that children have some mental construction of the tangible components of their bodies. Bearing that in mind, robotic inventions were described as being analogous to the human body. The entire Mindstorms kit centers around a 2 1/2 inch by 3 3/4 inch computer module called a LEGO RCX brick. The students were to think of the brick as the brain of the robot. There are sensory inputs and motor outputs, similar to a brain. Sensors for the RCX sense light and touch from the immediate environment. The sensors and motors were connected to the brain using wires, much like a human's nervous system sends messages to and from the brain. A wide array of additional LEGO pieces, including wheels, axles, gears, beams, and connector pegs and plates allowed students to create robots that function autonomously.

Children's brains are filled with stories that they have either read to them, or that they read for themselves. LEGO's "book," which tells stories to the LEGO RCX, is an object-oriented program developed by Tufts University called ROBOLAB (see Figure 1). The software was built on National Instrument's LabVIEW® software. ROBOLAB's versatility was demonstrated by its various programming and corresponding levels of abstract object-orientation. The intent of the software was to inspire and spawn *idea power* using a minimum of four learning styles: visual, auditory, intrapersonal, and

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[37] Pam Silverthorn, "Jean Piaget's Theory of Development" 1999, The Hellen A. Kellar Institute for Human Disabilities, George Mason University, 3

interpersonal. For younger children, whose logic is often single-tracked and irreversible, the linear programming language of Pilot, levels 1 through 4, was used (see Figure 2). Young adolescents, who according to Piaget should be more logical and consider more than one perspective simultaneously, use the more free-form and abstract Investigator programming language (see Figure 3). Investigator is essentially a LEGO-specific version of National Instrument's LabVIEW® software. Regardless of the level used, the purpose of the program is to provide a set of instructions for the RCX to follow. Relying heavily on if-then clauses, the program tells the RCX what its motors and sensors reactions will be when an input is received.

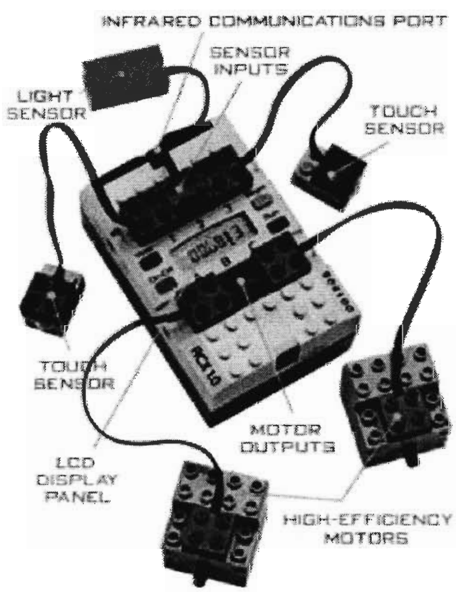

Figure 2. RCX with sensors and motors

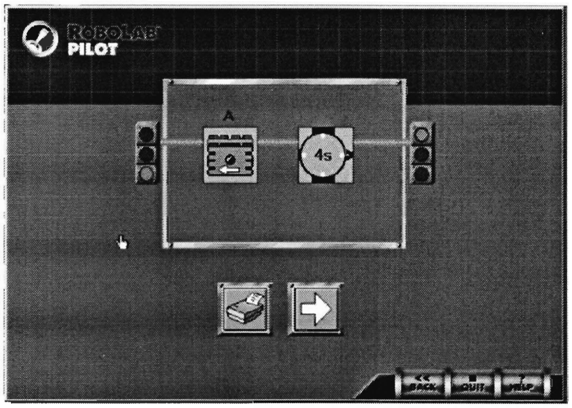

Figure 3. ROBOLAB Pilot

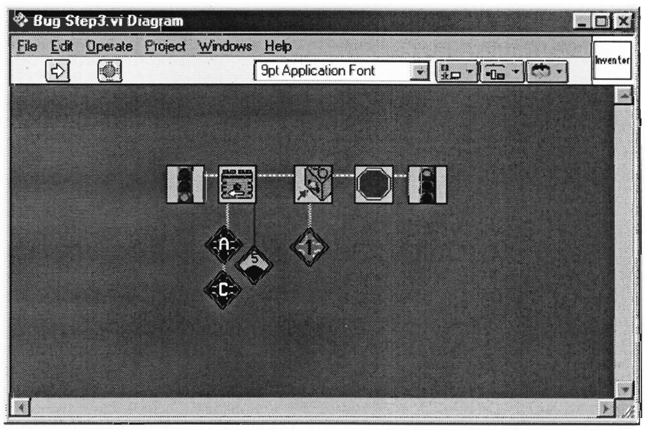

Figure 4. ROBOLAB Investigator

4.3. SATURDAY MORNING SPECIALS AND SUMMER SESSIONS

A team leader ran Saturday morning classes, in addition to help from two or three assistants. Class sizes varied; between seven to fifteen students per class was typical. The students came from both public and private elementary and middle schools throughout Worcester County. Their educational and economic backgrounds were equally varied. The children were separated by grade level. One class consisted of first through third graders, while forth through seventh graders made up the other. Each class ran for 75 to 80 minutes, depending on how long it took them to sort pieces at the end of the class.

	Grades 1 to 3	Grades 4 to 7
Session 1	Tank Bot	Gear Bot
Session 2	Gear Bot	Follow the Leader
Session 3	Monorail Jr.	Elevator 1
Session 4	Follow the Leader	Elevator 2
Session 5	Create-a-bot	Create-a-bot

Table 1. Saturday Morning Specials curriculum

Summer sessions enrolled similar students. Classes met for 75 minutes, five days a week. Curriculums for grades one through three were repeated weekly, while those for grades four through seven were repeated biweekly. There were instances when the younger would take consecutive weeks of classes. A sample curriculum is illustrated in Table 2.

		Grades 4 to 7 Week 1	Grades 4 to 7 Week 2
	Grades 1 to 3		
Monday	Gear Bot	Gear Bot	Monorail 1
Tuesday	Tank Bot	Tank Bot	Monorail 2
Wednesday	Double Bumper Bot	Double Bumper Bot	Elevator 1
Thursday	Monorail Jr.	Follow the Leader	Elevator 2
Friday	Create-a-Bot	Create-a-bot	Create-a-bot

Table 2. Summer session curriculum

4.4. STUDENT PROJECTS

Weekly projects were flexible enough to meet the presuppositions of all the students. Some students had never used Mindstorms before, while others were familiar with the product, and still others were well skilled at constructing LEGO robots. As a result, each week the instructional team would choose projects that had a powerful idea, yet the vehicles to constructing a mental image of that idea were as varied as the children's experiences. The motivational source of creating these vehicles, or robots, to live within the LEGO pieces themselves (especially 1 X 16 beams). The projects therefore, tended to take on lives of their own once the students were allowed to construct at their own will.

By attaching goals to the powerful ideas, instruction must gain an appreciation for adaptation if it is to be successful in a progressive classroom. When introducing the powerful idea of pulleys, the student constructed elevators. The goal was to allow for an elevator car to move up and down an elevator shaft made from beams (and again, 1 X 16 beams were the most popular choice). The team allowed for the children to discover on their own that without attaching a pulley atop the middle of the shaft, the car would not rise straight and, consequently, not allow for imaginary passengers to get on and off the various floors of the building. A thirteen-year old student surprised the team by thinking more abstractly than anticipated. Recognizing that it was a horizontal force causing the car to move horizontally, the student concocted a way to have a weighted LEGO brick inside the car provide an equal and opposite force. The powerful idea was not lost in this exercise, but rather enriched by the ability of the instructors to teach in more abstract schemata, in this case, using free-body diagrams to assist in an explanation.

4.4.1. GEAR BOT

This robot consisted of a simple chassis upon which sat the RCX. Directly behind the RCX sat two motors on the same chassis. Both motors were attached to two tooth gears, the second of which had an axle through its middle, upon which the rear wheels were attached. The robot was chosen because of its gears. The team wanted the students to understand that while the motors were responsible for providing power for the robot, that power could be distributed to wheels indirectly through gears and axles.

An advantage of the Gear Bot was that it was simple enough that some students understood the directions and built it quickly while others had a more difficult time using a LEGO set unfamiliar to them. Those who finished relatively quickly were allotted more time programming using ROBOLAB. As with the robots, simple commands were given to the students. The goal in terms of programming was to teach the students to make the robot go forward for a certain length of time using a time restraint.

4.4.2. TANK BOT

The Tank Bot has been heralded as one of the most investigative activities. This robot has been notorious for being a very sturdy construction. The chassis is much stronger than the Gear Bot. In addition, the use of treads instead of wheels introduced the concept of friction. Students learned that the robot would be "tougher to stop" but would not move as quickly.

The treads on the Tank Bot largely inhibited any side-to-side movement but helped it move on inclined planes. The team decided to introduce the concept of turning to the students. There were two separate ways to accomplish this task. Because the robot does not have any type of a steering mechanism, the only way to make the robot turn was to adjust the speed and/or direction one of the two treads. By varying the speeds while both treads moved forward, the robot would turn with a wide radius. Once the students discovered that by reversing one tread's direction would make the robot pivot, a touch sensor was provided to them. Using the touch sensor and a connecting wire, they made a remote control that would tell the brain to reverse the direction of the robot. To do this, they created a sensor control in their programming. Once the sensor was depressed, one or both treads would reverse directions. The students quickly realized that they needed to create a time limit or else their robots would spin in circles. As an incentive, students who successfully completed their program were allowed to run their robot in a maze of wooden blocks built by other students.

4.4.3. DOUBLE BUMBER BOT

The Double Bumper Bot was a logical bot to build because it reinforced the idea of a touch sensor, added another one, and allowed for the programming to become more advanced. The basic robot was the same as the Tank Bot, per the instructions. However, the students were encouraged to find new ways to reinforce the chassis and to attempt to replace the treads with wheels. This was an attempt to wean the students from relaying on visual instructions given to them and entice them to be more creative. Most students heeded the suggestion and attempted to make a type of "monster bot" with the largest wheels they could find. Once some found that their new designs didn't work with the bumper, they abandoned their cause, deconstructed their robot, and built according to the instructions. The team decided that it was important for the students to be creative and tried to work with them to make their own constructions operate correctly.

The Double Bumper Bot used both a front and a rear sensor. For all intents and purposes, the sensors were supposed to be independent of one another. However, up to this point in the class, the students had been using Pilot. Pilot's programs read much like a book. They were linear programs incapable of performing more than one operation at a time. Investigator, with its increased flexibility and user-defined tasks, was more appropriate for this project. Investigator allowed for the user to program two separate tasks to occur simultaneously, through the use of a programming tool called a fork. The Double Bumper Bot was an excellent example for when a fork would be appropriate. Once students built the robot and the bumper system, they were given a brief lesson on the essentials of using Investigator. Students attempted to use Investigator to program each sensor to be independent of the other. The result was a type of bumper car that spun for a certain amount of time after either of its bumpers was depressed and then moved forward.

4.4.4. FOLLOW THE LEADER

Follow the Leader demonstrated the use of the light sensor. The students were allowed flexibility in building their robots. They were given the instructions to the Gear Bot chassis and were told to mount a light sensor on the front. The light sensor was to face the floor.

The powerful or original idea for this project was one of the most advanced given tasks given to students to this point in the curriculum. Lines of tape were placed at intervals of three and six feet. Students were to use their robots to move three and six feet. Although not told to directly, it was expected that they would use time as the controlling variable. They were then given an arbitrary distance known only to the team. The students were not allowed to use their light sensor to make the robot stop on the line. They had to figure to use the time constraint on ROBOLAB. The original idea was the correlation between time and space. To a student, the connection is not physical, but rather a mental one. This level of abstract is one that Piaget would argue is only achievable once a student is in his or her formal operational stage, well out of the sixth grade.

4.4.5. MONORAIL AND MONORAIL JR.

The monorail robot demonstrated the first time that students' robots were not moving on the floor. Instead, the cars were built so as to ride along a rail spanning approximately one foot between supporting columns that were approximately six inches off the mounted plates. Students were to build both the car and at minimum, two sections of rail. The idea behind the rail was the balancing of forces; the weight of the car, its mass multiplied by the gravitational constant, would cause the rail to snap unless students supported the track in the middle of the span.

The light sensor was used to control the cars. They were programmed to stop at the end of the line to pick up customers at the station. They were to wait for the passengers to board for a set amount of time, travel down the line, and drop off customers. In order to make the monorail stop, a light was placed at each station. The light at the end of the line would be tinted red, while the others would be either green or yellow. Students would have to determine the amount of light that their sensors were noticing so as to set their program to the correct number. If they were not careful, their car would not see the light at the end station and would proceed to fall off the track.

The Monorail Jr. Project was used by the instructors for the younger grades in order to save time. The construction of both the car and rail took up the majority of one session. Bearing in mind the theory that the students have an equal opportunity for discovery during operation, the team built the rails for the students prior to the session.

4.4.6. ELEVATOR

The elevator project combined various knowledge structures or original ideas. Each idea, once realized during construction, assisted the student is building an elevator that was not in peril of collapse and safely transported passengers from one floor to another. Students were shown an example of an elevator developed by Sean Waithe. Rising nearly three feet in height, the structure demonstrated three physical structures: moments, levers and the use of pulleys. The instructional team determined that these mental structures would have to become realizations in the consciousness of the students if they were going to make an elevator that both stood and was capable of carrying passengers.

Imaginary passengers of the elevator would call for the floor they wished to go to. In reality, their selection would turn on a light mounted near the opening of the shaft on one of the floors. A programmable RCX which controls a motor and the accompanying shaft holding the string, would then operate until a light sensor attached to the elevator car senses the light, at which point the car would stop to allow passengers to both embark and disembark. After some user-defined delay, the elevator car would return to the lobby. Braking mechanisms were touch sensor depressed once the car reached either the bottom or top floor. This program demonstrated the use of sensors as a safety measure and a controlling mechanism. Integrating both touch and light sensors would be equally effectively in either Pilot or Investigator. While Pilot may seem like a more sensible program, Investigator produced a more efficient program with the capability to expanding and manipulating factors and controls easily. The level of sophistication in systematic manipulation of symbols, in this case, pictures, will go to either proving or disproving Piaget's theory of cognitive development. If the student realized that he or she could turn various sensors on or off, such as in the event of a fire, then they would have realized the correlation between the symbol on the screen and the physical sensor on the elevator shaft.

4.4.7. CREATE-A-BOT

The last sessions, in which students were allowed to create any robot that they wished, required that the robot meet certain universal goals. The session emphasized demonstration of previously realized original ideas. Essentially, because of the limited time with the children, this final project was the team's method of receiving feedback as to what the children learned. Because the course was structured in a way that either the immediately previous one or two sessions were centered around a relatively unmovable object, students tended to build items with anywhere from 1 to 10 wheels with up to 16 gears.

The needs for adaptive, proactive teaching were realized during this session. This is one of the most important concepts for this session. The original ideas that the students acquired during previous sessions required prodding from the team to surface in their minds. It was widely regarded amongst the team that the original ideas were molded to the robot that had first demonstrated the idea. For instance, children had to be reminded that they had used gears to turn axles, and in turn, the wheels attached to those axles during the construction of the Gear Bot.

The two primary goals for the robots were that they had to be both operational and anomalous. The robots were to react with each other, and whoever's robot had the best reactions to interaction was deemed the winner. Predictably, many of the students dissolved these goals to meaning *robot wars*. To combat these aggressive thoughts, students were told that their robots were peaceful and could not be used to destroy other robots. Rather their robots had to outthink the other robots. Mazes were constructed, alternating terrains developed, and physical barriers were setup. Because the RCX is capable of a lot more than just reacting, the students were given additional assistance with programming their robots. The team would present alternative goals to the children, and allow them to match those that were most agreeable with their mental constructions of their robots.

Patrick Spencer

5. RESULTS

5.1. A Sample Curriculum in Light of Noted Observations

There are some assumptions that are inherent to this curriculum. Any of these factors can all be altered to match the time, need, and resources of any teacher. It is assumed that the class is of similar composite as that described in the methodology. This imaginary class meets for five sessions, with each session lasting 75 minutes. The classes are divided by grades. Grades 1 to 3 constitute one class, while grades 4 to 7 make up another. However, the curriculum developed herein is adaptable enough to meet the needs of any groups of students.

The robots are the vehicles by which an original concept or idea is demonstrated to the students. Less abstract ideas, such as the use of gears, can be demonstrated during construction. Other concepts such as surface friction on inclined planes, requires that the student complete construction before the idea even have an opportunity for realization. Therefore, it is imperative that the teacher identifies the ideas that he or she wishes to cover in the class. These ideas must be successfully conveyed to the team. If these ideas are abstract, and require much manipulation and use of a completed robot, then construction activities should be hastened as to provide time for this self-realization to occur. Teachers may even consider constructing part of the robot for the students. In the case of the monorail, the concept of balance or equilibrium of forces was considered important to the instructional team. To hasten construction, the rail upon which the monorail car would ride was constructed for the younger students before class began. Original ideas and their self-realization should be paramount to any other activities that students complete.

The focus of this curriculum is an integration and increased exposure to the various learning styles. The idea behind this focus is that an environment can be created using LEGO Mindstorms for which all students can have the capacity to expand their mental structures. Therefore, the classroom environment is considered as important as the robots that the students build. The environment modeled in Figure 1 demonstrates the setup for classes at the Bancroft School.

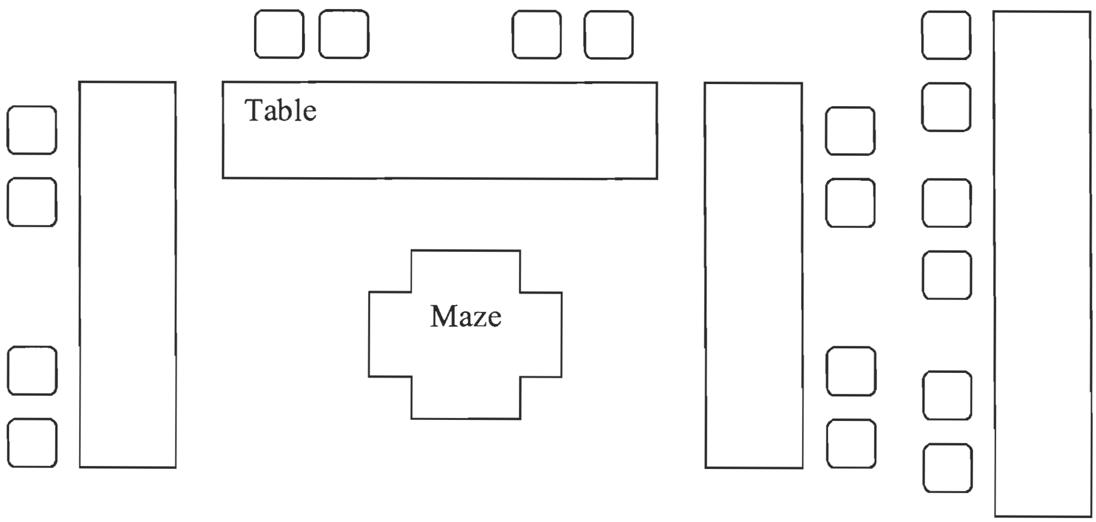

Figure 5. Bancroft School progressive LEGO classroom

Students should work in groups of two, with initial roles assigned to each student. One student is the supplier of pieces, while the other is the mechanic, putting the robot together. If possible, an experienced LEGO Mindstorms user should be partnered with an inexperienced user. Additionally, the experienced user should begin the session assuming the role of the supplier, so as to familiarize the other student with the names of the pieces. Students favoring interpersonal learning styles and auditory learning styles will be most receptive to this environment. Intrapersonal students will want to work on their own. It is the role of the teacher to distinguish students who learn more effectively this way from students who are being greedy and stubborn about their robots, and in turn, ideas. Students demonstrating the latter qualities should be encouraged to work with the least experienced students, and assume the role of a mentor. It was found that this title gives them a sense of prestige and importance. The instructional team must monitor the group to ensure that the stubborn student is not imposing on the inexperienced user, but rather that collaboration is ongoing. Interpersonal and auditory learning can be combined to encourage collaboration and verbalization of students' mental structures.

Visual learners are able to consider information's context, layout, length and processes described.[38] Students who primarily learn using these skills have been a target of LEGO Mindstorms project creators since its inception in 1998. The LEGO Group includes three-dimensional step-by-step instructions for various robots with the Mindstorms kit. These instructions are primarily drawings of the robot in the various stages of development. Pictures of pieces required for the steps are given as well. Some students will be able to analyze the pictures and be able to mimic their robot to look like it. The most difficult aspect of building in this manner is constructing the parts of the robot that aren't viewable from the drawings. Some texts have tried to address this by showing alternative views of the robots at various stages.[39] It is the opinion of the writer of this paper that students confuse the various views as additional steps and attempt to make their robots mimic each picture as they view it. Arrows or other means of visual direction need to be made more dimensional so as to clearly show the constructor the difference between steps and alternate views. Otherwise, students must map their way through the instructions in order to complete the construction. On another note,

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[38] United Kingdom Standards, 4
[39] Jonathan B. Knudsen, *The Unofficial Guide to LEGO MINDSTORMS Robots* (Sebastopol: O'Reilly, 1999)

instructions in color seem to demonstrate how pieces go together more clearly. Four beams stacked atop each other, when viewed at an angle in black and white, looks like a wall if the beams have relatively similar hues. Colored instructions show where pieces go together, and allows for students to count more easily. Children's use of visual instructions, in the case of LEGO, leads to more practical, physical learning. In other words, creativity is often stifled as the students attempt to simply copy the pictures.

Kinesthetic learning, that is moving things around, is synonymous with construction. Anytime the students attempt to build, they are moving thing around and attempting practical experiments. From the viewpoint of the teacher, these experiments tested the students' abilities to facilitate self-realization of goals. To the student, they were trying to have the robot do what in their heads it was meant to do. Again here, the role of the teacher is not minimized. The teacher must develop a balance of creating an appropriate scenario for the discovery of an idea, and keeping the students on schedule. Luckily, it was noted that LEGOs often kept students engaged in activities for the entire session. Children should be encouraged to experiment. It has been the experience of the writer of this paper that students prefer structured learning environments to those in which they must use their creativity to create object. When the elevator project, which had no tangible instructions, followed robots with explicit building instructions, the task was poorly received by students. Their concern was eased somewhat by the presence of a fully operational elevator built by the instructional team using LEGO Mindstorms. Students should be encouraged to not merely copy either the instructions or another robot, but instead, use them as a catalyst for ideas for their own construction.

Some students are disengaged from the learning experience using LEGOs. At Bancroft, a small number of students (an average of one per five sessions) would not want to use LEGOs to construct robots. Some had a negative view of the class because their parents signed them up for the class against their will. Other students had boundless energy that they wished to expunge, while some were lethargic or seemingly tired. These students pose a unique opportunity for teachers. These students have a pre-disposition for intrapersonal learning, at least in this setting. The most difficult task for a teacher is to get the student to reflect on their feelings, and understand that they can both learn and have fun building LEGOs. Students who express disinterest or disdain for the current project should be encouraged to work on a similar project on their own. That means that teachers should always have a contingency plan in case a project is an utter failure. For instance, students who were uninterested in building the gear bot were encouraged to build a double bumper car. The concepts behind the robot were the same, and the additional bonus of a bumper made the robot seem more uniquely theirs.

If students are building different robots, it is important that the robots are capable of maneuvering in similar fashions. This also presents a unique challenge to teachers. Dissociated students should not be enticed with a project that is grandiose in scale when compared to the project that the majority of the students are working on. This is unfair to the other students. When they realize this, they too will become rowdy or uninterested with their project. Teachers need to be ready to provide students with tools that will be both educationally relevant and fun. For instance, when students building the gear bot realized that some of their peers were essentially building a bumper car, they felt that their robot was less maneuverable. As an incentive, the instructional team informed them that once they got their robot to complete as task, they would be able to add a remote control to their car. The remote control was a touch sensor attached to the RCX with a long wire. When students depressed the sensor, the robot would turn by stopping one of the motors. Students could choose to use either time or a second depression to start the other motor again. In the end, both robots had an input sensor that responded either right before or after the car would hit something. Once all the students had completed their robots, the bumper cars could maneuver in the same course as remote cars, with similar results.

5.2. Students demonstrating the various learning styles

Each of the learning styles was represented in the class. Visual learners, in keeping with the societal norm, were the most common learner. As the class was centered around building robots, kinesthetic learning was inevitable. Each student was given an opportunity to build the robots, and experiment with moving pieces around. Teaming the students in groups of two facilitated interpersonal learning, as well as auditory learning.

5.2.1. The Kinesthetic and Intrapersonal Learner

Evan was a nine-year-old male student from Worcester. Evan was quiet, but very alert. He was always wide-eyed and seemed intent on watching his partner construct the robot. He was not distracted, but seemed complacent with simply observing. At first it was assumed that Evan was, therefore, a visual learner. When the team recognized that Evan was passively participating in the class, they offered that Evan construct the robot using the instructions given to each team. His partner, happy to oblige, became the supplier while Evan began construction. However, it became evident that Evan could not make sense of the three-dimensional pictures. The team attempted to coax him, pointing out the pieces in the picture, and orienting the robot as it is shown in the instructions. None of the techniques appeared to be successful. Reciting the instructions to Evan and providing a verbal explanation of the steps was equally as ineffective. However, once the function of the robot was explained to Evan, he began experimenting with pieces until they reflected his understanding of the robot's function. He understood that a bumper was necessary to protect the robot. He could not mount the bumper in the manner that LEGO intended. However, he recognized the role of the bumper and found his own way to attach it to the robot.

Evan demonstrated that teaching students can be an exploration, but always aimed at producing a common result. Before the class began, it was assumed that the students would all be able to read the "simple" instructions. Evan taught the team that exploratory building and reflecting on the function produces the same results as looking at a set of instructions.

5.2.2. The Interpersonal and Intrapersonal Learner

Monique was a 10-year-old female student from Worcester. Monique was patient and interacted well with the other students. During the construction of the robot, she would make suggestions that were out of line with the current state of the robot. For instance, while the chassis was being built on the Tankbot, she suggested adding the treads. Her ideas were not wrong, but their timing was random. However, she was paying attention to the construction, and later, programming. During programming, Monique's feedback to the team's questions and her reflections caused an understanding of an abstract idea that shocked the entire team.

Once the Gear Bot was built, the team members decided to attempt to lead the students to discover pivoting. The most common way to make the Gear Bot pivot is to program the motors to operate with opposite, but equal, rotational velocities. A more advanced and abstract means of achieving the same end is by stopping one motor while the other retains its velocity, and a pivot wheel is used to cause the robot to spin about its axis. This is precisely what Monique offered be done. It turns out that Monique's mental structure included her experience riding on the front of grocery carts at the store. She remembered that her mother could turn the cart in a complete circle without seeming to go anywhere. Monique took a mental structure and adapted it to the robot. Her experience helped shape her education. This is precisely what Dewey, Piaget, and Papert had in mind.

5.3. Original Ideas

Science / Engineering Original Idea	Science / engineering topic	Engineering definition[40]	Projects displaying idea	Massachusetts Science and Technology / Engineering Curriculum Framework
Force	Dynamics	Any kind of push or pull on an object	Gear Bot, Tank Bot, Double Bumber Bot	Physical Science, Grades PreK-2, **4**
Inertia	Dynamics	The tendency of a body to maintain its state of rest or of uniform motion in a straight line	Monorail, Gear Bot, Tank Bot	Physical Sciences, Grades 6-8, **11**, Physics, Grade 9 or 10, **1.5, 1.7 1.10,**
Torque	Lever	The moment of a force. Also known as the	Elevator (shaft)	Physical Sciences, Grades PreK-2,

[40] Douglas C. Giancoli, *Physics: Principles with Applications,* 5th ed. (Upper Saddle River: Prentice Hall, 1998)

		product of *force times the lever arm*		**5**, Engineering Design, Grades PreK-2, 2.2,
Static Friction	Inclined plane	Microscopic contact between surfaces which *prevents* movement	Tank Bot, Modied Gear Bot	Physics, Grade 9 or 10, 1.9
Kinetic Friction	Rubber wheels	Microscopic contact between surfaces which *impedes* movement	Tank Bot, Gear Bot, Double Bumber Bot	Physics, Grade 9 or 10, 1.9
Rotational velocity	Axle	Signifies the speed and time measured around an axis of rotation, most commonly referred to in radians	Gear Bot	Physics, Grade 9 or 10, **1.1**
Velocity	Moving bodies	Signifies the magnitude of how fast an object is moving and the direction of movement	Monorail, Elevator, Follow the Leader	Physical Sciences, Grades 6-8, **11**, Physics, Grade 9 or 10, **1.1**
Energy transformation	Work	The total mechanical energy of a system neither increases or decreases in any process. It stays constant – it is conserved	Elevator, Monorail	Physical Sciences, Grades 3-5, **5**, Physical Sciences, Grades 6-8, **13**, Physics, Grade 9 or 10, **2.1, 2.2, 2.4, 2.5**
Second	Time	1/86,400 of a mean solar day	Follow the Leader	Physics, Grade 9 or 10, **1.4**
Power	Motor	The rate at which energy is transformed [P = W/t]	Gear Bot, Tank Bot, Elevator	Physics, Grade 9 or 10, **2.4**
Symbols	Computer programming	Something that stands for or suggests	All ROBOLAB software	Technology/Engineering, Grades 6-8, 3.4

		something else by reason of relationship, association, convention, or accidental resemblance		
Equilibrium / balance	Statics	Forces on an object are equal and opposite	Monorail, Elevator	Physical Sciences, Grades PreK-2, **5**, Physics, Grades 9 or 10, **1.8**

Table 2. Original ideas, corresponding physical concepts, and their definitions are described. Their relevance to the curriculum and the Massachusetts Framework are also provided. **Bold** items indicate core requirements for successful completion of the corresponding strand.

6. PROPOSITION AND DELIBERATION

Teaching in a progressive classroom requires a proactive attitude, and can be relatively simple-minded, as long as the original idea is not lost in either the construction, programming, or operation of the robot. Adequate preparation is the most important aspect of a progressive classroom. The teacher must have an awareness and understanding of the original ideas, and more than one plan for delivering the ideas to the children. Fortunately for the teachers, children's mental structures will always be less developed than their own. Otherwise, as we got older, our views and mental structures would be taught by children. The irony therein is that it is possible for children to expand adults' mental structures. But currently the idea is not developed to the point at which we would label children as teachers. Developmentalism, and constructionism, offer opportunities for children and teachers to interact with increased feedback from each other. This is itself a form of interpersonal learning. Critics believe that these educational philosophies result in an unstructured learning environment. Establishing goals from original ideas by establishing how the idea is conveyed in educational standards or frameworks. Teachers should be prepared to teach students an idea through the use of abstract symbols and the construction robots, rather than one or the other.

A teacher can control certain elements of an educational experience, while others are beyond their direction. Nonetheless, teachers must strive to make a learning environment as ideal for students as possible. A number of propositions, intended to only enrich the experience of children and expand their mental structures more vividly, are presented herein.

- Classroom dimensions

    - Increased class time
    - Feedback / circle discussion
- Outside dimension
    - Take-home projects
        - Pre-developed construction kits
    - Pre-class survey
        - Children
        - Parents

As both Piaget and Papert note, children can be stubborn. Children's ideas have strong, coherent, and logical convictions. It takes time to express original ideas to children through separate vehicles because children's responses are also unpredictable. It takes time to determine the level of knowledge and understanding that each student has achieved. To that end, it is proposed that more time be allotted in class. Because construction and programming robots will only present the children with the opportunity for discovery, they need time to interact with the robots and see how they work, as well as how they don't. This will lead to further investigation, modifications, and eventually, successful operation. After the successful operation of the robot, the original idea should be evident. Children's stubborn attitude needs to be accounted for when determining how long a concept is going to take. Projects can take approximately 1 hour to build, and at least 1 hour of investigation. There also should be time allotted for feedback, which a teacher needs when considering teaching concepts again.

Feedback from students is an invaluable test of a teacher's effectiveness. Original ideas, which are central to the entire project, need to be conveyed, either through symbolic representation, such as language, or in more abstract terms, such as free body diagrams or drawings. Feedback, when structured by a teacher, will demonstrate whether or not children came to a realization of the ideas, and by what means. This will in turn shape how the lessons and ideas are presented in the future. Every teacher can remember a class lesson or idea that was ineffective. The first time that the elevator project was completed, it was largely unsuccessful because the children were used to having certain types of instructions. When a project was given with no drawn instructions, the children were surprised and unprepared for the delivery method. This was a surprise to the entire team, because it was anticipated that the children would jump at the opportunity to use their creativity with the project. The curriculum was altered so as to encourage more internal visualization of projects in earlier sessions. The placement of the elevator project in the curriculum was not shifted. During the next class sessions, students were much more at ease about not having a set of visual instructions. The students' projects became very personal to them, and they were often times disappointed at the thought of having to deconstruct their inventions.

Children's motivation to learn and discover should be nurtured, and encouraged to continue when discovery is happening. The student's robots had characteristics that the student wanted it to. When building the gear robot, some students used large tires while others experimented with treads, and still others tried to use rims alone. The colors used, the add-ons, and the LEGO men and lights added, all reflected the personalities of the children and encouraged them to keep building. Children should be allowed to take home pre-determined kits with the intention of building a robot so as to either further demonstrate an idea or to enlighten the child as to new ideas. Because LEGOs and robots have the connotation of being children's toys, they will feel as if they aren't learning, but rather, just having fun. Because the class is taught on either the weekend or during the summer, children would have ample time to complete these projects, and bring them into the following class for demonstration purposes. This would be another form of feedback for teachers to be able to determine if students are actually understanding the original ideas. That said, the writer of this paper is not naïve to the fact that the construction kits cost a lot of money. However, children may not need all the pieces in a kit in order to complete a home assignment. If teachers prepare curriculums ahead of time, then there is more time to determine if enough pieces are available, and what any additional needs are. Children who take the robots home and learn in a different environment will be more comfortable using LEGO Mindstorms.

One of the most difficult decisions as a teacher is how to prepare a curriculum that meets the needs or the most students as possible. Students who are well equipped with and understanding of LEGO Mindstorms, and the LEGO language, most often construct the robots faster, and are more adept at using the software. This does not mean that they will come to realize the original idea any more quickly than students unfamiliar with Mindstorms. Rather, there appeared to be a healthy rivalry amongst groups to see who can finish their robot first. Students who construct at a slower pace often were discouraged to see other groups playing with their completed robots. A pre-class survey sent to both the students and their parents should determine two things. First, the results should tell the teacher the amount of experience their children have using LEGO Mindstorms. If the child has experience, it is important to know under what conditions. Using Mindstorms in the classroom is much different than using them at home. The amount of supervision and assistance, the amount of genuine desire to construct robots, as well as the number of pieces available, will dictate how creative the student most likely will be. Regardless of the student, there was tremendous pride anytime a project was completed. This was the case so often that it became commonplace for the parents to come into the classroom at the end of the sessions so that their children could show off their inventions. Secondly, the results would help the teacher in determining pairings of students for projects.

Students with experience with LEGOs should be teamed with those with little or no experience. The intent here would be to allow the students to learn from each other. Some may argue that this idea would lead to one student dominating the construction and programming. This is a viable concern that is solved two ways. One way to prevent this from happening is by carefully monitoring the student's progress. The instructional team members were assigned to no more than 2 groups at a time. They carefully monitored who was building the robot, programming the robot, and using the completed product. They would offer suggestions to the students once establishing what the students were trying to accomplish. At no time, however, did they build the robots for the students. The second way of combating one student dominating one or more methods of construction was to assign each student tasks. Building and programming the robot requires a number of steps. The instructional team would assign tasks to the students with the use of the analogy of a car mechanic. During some steps, one student would be asked to be the supplier. The student would be responsible for gathering the pieces necessary for those steps. The other student would be responsible for taking the pieces supplied and use them for construction. The students would switch roles every other step. It was the job of the instructional team to ensure the transition of roles went smoothly.

7. CONCLUSION

The classroom should be a place where discovery takes place. Students of any age should have the opportunity to manipulate objects both mentally and physically in order to broaden their understanding of the world. The class should be interactive, allowing students the opportunity to grow both individually and as a group. Having multiple understandings and mental images of an original idea is the pinnacle achievement, and should be the goal of any teacher. This means that an understanding of the various facilities of learning is necessary. The original ideas can come from any subject, be it mathematics, philosophy, physics, or Native American studies. To borrow an analogy, examples are the vehicles that will drive home the original idea. Projects, or examples are a physical interpretation of a student's understanding of that idea. For instance, little Johnny may associate power with a motor. The motor, therefore, symbolizes power in his mind. Students should not only be given examples, but construct them themselves. The self-discovery that can occur during these monitored experiments is one of the most important aspects of progressive education, as detailed by Papert, Piaget, and Dewey, amongst others. If little Johnny builds an elevator, he may come to realize that pulley can assist in doing work. His previous mental construction has now expanded.

Papert's philosophical pedagogy suggests that teachers are the single most important contributor in the classroom. While children should mold their examples themselves, teachers should be assisting students in coming to a more rich understanding of an idea in terms of the student's capacity. This requires a certain level of flexibility in both curriculum development and implementation. However, the teacher's ability to teach and understanding of what it is like to be a child will be of great assistance. LEGO Robotics offers a flexibility that will help students come to a more rich understanding of physical concepts and how to interact with others.

The class for which the writer of this paper taught and studied took place at the Bancroft School in Worcester, Massachusetts. Classes consisted of students aged 6 to 10 and 11 to 13, meeting in groups of approximately 12 students. The class met for five sessions, each lasting approximately 1 hour and 15 minutes (plus clean-up time). The class was divided into groups of two, with students being grouped by similar ages.

The classroom environment was a large all-purpose room with large rectangular tables set-up in a horseshoe fashion. Computers were setup along one wall. The kits that the students used were *LEGO Mindstorms for Schools*, purchased by the Bancroft School through the education assistance company Pitsco. Their website, www.pitso.com provides an on-line catalog of pedagogical tools for both educators and students. The software utilized in the class was *ROBOLAB for Schools*, developed by Tufts University School of Engineering, and distributed by LEGO Educational division. This object-oriented software provided the best graphic-user interface for children of all the software available at the time.

Original ideas are intellectually fundamental concepts upon which more complex and abstract concepts, theories, and technology are based. The concept of original ideas is a term derived from the study of Papert's work. Original ideas should be at the forefront of a teacher's mind when leading a session. Although the terminology may not be understood by the student for years to come, it's the physical act that is the definition of the term that is important. No two students will have quite the same understanding of any topic, but that is not of concern either before or during construction of their robots. The goal of the teacher is that the students work together to reach a more fulfilling understanding of the concept. Therefore, although the end results may all look different, if the robot operates appropriately according to the original ideas known to the teacher, then the project is a success. The project will fail only if the students are not monitored and reminded of the aim of the project. However, students' progress must be evaluated with the different learning styles kept in mind. The benchmark for successfully learning a concept is different for each learning style.

Some students will learn by reading the instructions, while others may need them read to them. Still other students will learn more efficiently by touching the various pieces, and some will have to talk to other students and reflect on what the other students say. It is the role of the teacher to identify the learning styles of the children, and assist them in that manner. The nature of the classroom will force the students to use interpersonal learning styles. However, other learning styles must not be forced upon the student. If one does not work, another must be attempted. It is important for the teacher to keep in mind that the building and operating the robot is not a race, but an opportunity for discovery in the mind of the builder. Projects must be flexible in their timeframe. Depending on the intellectual level of the student, some projects will be built quickly while others may take more time than the teacher initially allotted.

The examples mentioned in the Appendix should be used as a tool, not a guide. They are intended to assist a teacher in how to think about building a curriculum, in light of the theories of progressive education. Any of these projects can be used, and adapted, to fit the needs of any class. Pre-class activities are intended to have the student begin thinking less abstractly about an original idea by comparing it to a topic they are already familiar with. By teaming the original idea with a human aspect, students can attach their past experiences with a new topic. This is much the way that adults learn new ideas. The construction activities and post-construction activities are intended to present the original idea in a more abstract, unfamiliar manner. The fact that the projects are constructed out of LEGO pieces makes the entire process very enticing for students (and at least one teacher).

The educational theories of Papert, Dewey, Piaget, and like-minded philosophers stress the importance of experience in education. Students' construction of robots using LEGO *Mindstorms* enables them to realize ideas through discovery that is tempered by the appropriate guidance from one or multiple teachers. Curriculum development should be flexible and allow for students to acquire the knowledge they will need in future educational experiences and after graduation.

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9. APPENDIX A: CLASSROOM EXERCISE – GEAR BOT

9.1.

The Gear Bot is typically the first or second robot constructed by students. The construction is relatively simple, and the resulting robot very adaptable. What follows are suggested ideas and activities for the teacher to complete before, during, and after the class.

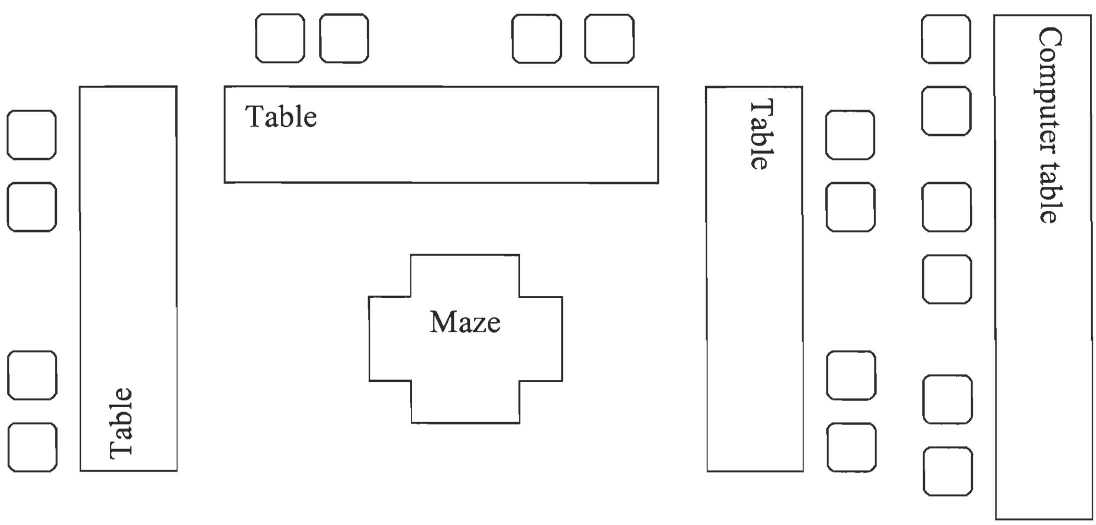
9.2. Pre-class activities

Some students will never have used LEGO Mindstorms before joining the class. There are pieces that students must become familiar with before they can begin construction. How certain pieces go together are important as well.

The writer of this paper has used students as embodiments of the various robot components. The students enjoy this role-playing exercise, and it helps them in understanding how the robots will work. Purchase one yellow t-shirt, 2 grey t-shirts, and one blue t-shirt. Using iron-on letters or a felt pen, label the yellow shirt "brain," the grey shirts "motor a" and "motor b," and the blue shirt "touch sensor." Purchase six 16-ounce plastic cuts, preferably black, and black string. Make three sets string telephones.

In the interest of saving time, as well as not losing pieces, the instructor should collect the LEGO pieces necessary for the complete construction of the robot, and place them in some sort of a bin for each group. If there are to be add-ons to the robot, such as a bumper, include those pieces in the bins as well.

Supervision and advice on the behalf of the instructors is crucial during the first session. For this reason, arrange the tables in a horseshoe shape, leaving a large open space in the middle of the three tables. This way, the instructors can move between tables and supervise the children more closely. In addition, the space can be used for students to operate and manipulate their completed robots. The Bancroft instructional team even constructed mazes using wooden blocks in the central space. This is recommended, so that students can investigate their robot's responses to the immediate



environment. Off to one side of the room should be a table dedicated to programming. The Bancroft team had three computers setup at the ROBOLAB prompt for students to use for programming.

9.3. Pre-construction activities

In the first class, students should come to realize the following

- The components of the robot
- How the various components of the robot interact

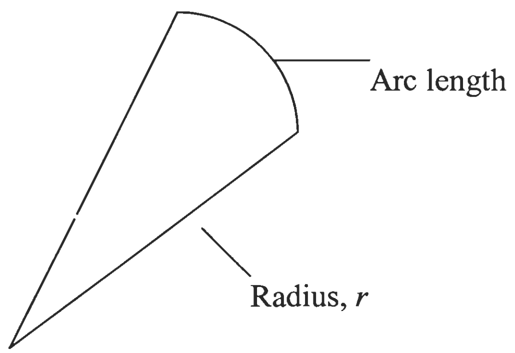
  - How does the robot move?
  - How does the robot sense other robots or objects?
- The physical limitations of the robot in terms of movement
  - How does the robot move backward?
  - How does the robot turn?

At the beginning of the first class, show students a completed Gear Bot and let them pass it around, in order that they can examine it at their will. Demonstrate it moving along the ground. The most effective way of explaining how the robot works is by using the analogy of a human. The RCX is the robot's brain; it tells the robot what to do. It knows what to do by assessing its environment. At this point, an analogy to something the students most likely already understand is made.

It is assumed that the children understand certain symbols. Specifically, consider the symbols used by a police officer directing traffic. Universal signs for stop have been discernable by children. Instruct the child to imagine they are about to cross the street with their parents. To cross the street they must look at the police officer for direction. He or she knows the symbol that the officer is giving by using his or her eyes. This is how a sensor can be described. The sensors are the eyes, ears, nose, and hands of the robot. They are how the brain knows what to do. Once the children understand this, assign one person to be the brain. They wear the yellow shirt. Suggest to another student that he or she be the eyes, nose, ears, or hands of the robot. Give this student the blue shirt. Ask the students how this human will move once the officer tells them it is safe to cross the street. Once legs have been identified, the equivalent component on the robot must be determined. The motors are the robot's legs. Depending on the age of the group, students may be able to assimilate that both legs and motors exert force over a distance, and therefore, do work. Luckily, the Gear Bot uses two motors, making the analogy of legs easier for the students to comprehend. Give two students the grey shirts, and invite them to stand aside the brain, like the Gear Bot.

The teacher will now have a human representation of the Gear Bot. The children should not be allowed to talk to each other, except by using their phones. If the sensor "sees" a wall, it can't just turn around and tell the brain; the sensor must use its end of the phone to tell the brain it sees a wall. Similarly, the motors can't move without direction from the brain. The brain can't talk to them without using the phones to talk to them.

At this point, explain to the children this human robot only knows how to do three things: move forward, move backwards, and stop. This will present an interesting dilemma for the students. Instruct the human bot to move forward until it touches a wall. The teacher must check to ensure that the sensor "tells" the brain when it has run into the wall. Next, the brain "tells" the motors to stop moving forward. Remember, all the communication must occur through use of the string telephones. If the students' parents have granted permission, this process can be more clearly demonstrated by blindfolding the students, therefore forcing them to have to communicate verbally. To the rest of the class, ask how the robot can keep from running into the wall. The instructor should be attempting to have the students realize that with stiff axles, the only option is to differentiate the rotational velocity of the two motors. By having different angular velocities, the result will be that the robot will turn. Depending on the amount of the differential, the robot's arc will be of varying length. By alternating the direction of the wheels while maintaining equal speed, the robot will essentially pivot in place. This can sometimes be difficult to duplicate using the human robot, because the connections between the various pieces are much more flexible than on the LEGO robot. Therefore, the teacher may have to rely on having students physically turning the wheels on the pre-built Gear Bot to demonstrate this phenomenon.



Pre-construction activities should last no longer than 15 minutes. At this point, students have enough information to be able to build a robot using a set of instructions. Students should be paired in such a manner as described in the methodology.

9.4. Construction Activities

A set of visually enticing instructions are provided for the Gear Bot from LEGO, and included in the Mindstorms for Schools construction kits. In giving the students only the necessary pieces to build their robot, they can learn the terminology of the pieces at a gradual pace. The chassis upon which the RCX will sit is the first component to be built. The instructional team prefers this chassis because it has proven to be more stable than some of the other chassis designs. The gears, which move the axles attached to the wheels, are the most important aspects of this project. The idea of angular velocity is demonstrated again using the gears and axles. As the radius, *r*, spanning from the axis of rotation to the edge of the gear decreases the angular velocity will increase.

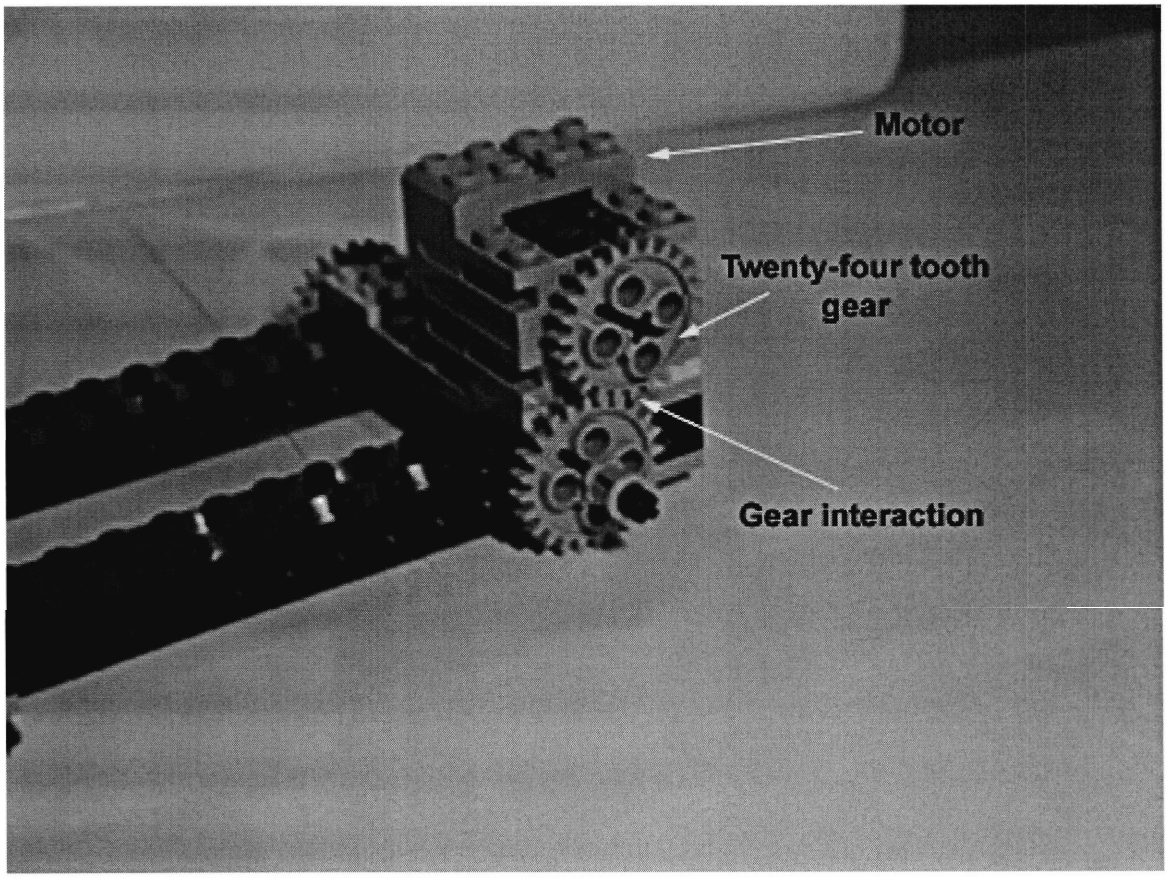


Figure 6. Gear demonstration

There are techniques and processes that can be utilized by teachers when addressing auditory, kinesthetic, interpersonal, and intrapersonal learning styles. The teacher must decide how he or she is going to use these processes in helping a student realize an idea. The Gear Bot should be pre-built by the teachers for the students to investigate. Teachers must be ready with verbal instructions for the students. They should take pictures of the gears, chassis, underside of the completed robot, as well as any section that was difficult to construct. Students should be encouraged to collaborate and discuss their robots with their partners. Assigning tasks to students will encourage interaction between the students, and lead to interpersonal and intrapersonal learning opportunities.

9.5. Unexpected Construction

There are components of projects that do not meet any stated educational standard, but affect the quality of interaction between the student and the educational tool. Processes involved with learning styles can be hindered by a student's lack of understanding regarding the instructions given to carry out the assignment. Each LEGO Mindstorms project at Bancroft provided a set of visual instructions. These visual instructions were the least flexible of all the types of instruction given. They allowed for the least amount of feedback from the students. On the other hand, students who learn by physically handling objects can be surprised at how unsound the completed LEGO robots can be. This section encompasses some general observations noted by the writer of this paper that may assist the teacher in making construction effective and efficient for the various learning styles. Because the wheels are not directly attached to the motors, axles must be utilized in the correct positions within the chassis. Students must be careful as to not place the axles in the wrong location, or else the tooth gears will not be in alignment in the later steps. Once the axles are correctly positioned, the gears can be attached. This requires some force, as both the gears and the axles are grooved. Be careful that students do not break their chassis into pieces because of excess force.

9.6. Programming

The versatility of the Gear Bot makes it an attractive robot. If students construct the bot quickly, there is the option of adding a bumper to the robot. For students moving more slowly through construction of the robot, a simple remote control is easier to construct, while essentially providing the same input. Regardless, understanding the physics behind the robot's movements is one of the most important ideas of this exercise.

ROBOLAB offers students the means of having a self-realization regarding turning. They know that they must be able to maneuver their robot about some maze. After having the robot hit a wall, back up, and hit the wall again, the students realize that in order to make it through the maze, the robot must turn. Short of physically moving it into alignment (remember the robots are intended to be anomalous), the students use ROBOLAB to "tell the brain what to have the legs do when the eyes see a wall." Think of ROBOLAB as a book. When the brain reads the book, it remembers the information and uses it in the real world. The Gear Bot should be programmed to perform the following sequential steps

- Move forward
    - RCX tells motors to move at the same speed, in the same direction
- Sense an impediment
    - Light – placement of lights at various positions along the maze
    - Touch – blockades impeding the current direction of travel
- Turn
    - Supply differential power to the motors. Alternate motor direction.
- Stop Turning
    - Time restraint
        - Clock
    - Touch restraint
        - Bumper – touch sensor
- Move forward

This linear program can be completed using ROBOLAB'S Pilot level. This introductory level will familiarize the students with the various symbols for sensors, motors, power levels, direction, loops and time constraints. The program itself reads in a liner fashion, like a book. Alternatively, the program could be completed using Investigator, if the teacher believes that the children are capable of relating the symbols and being capable of realizing the tasks with the non-linearity look of the resulting program.

If the students choose to build a full bumper for their robot, they have two options for a constraint on turning. They can choose to use a time constraint, waiting for a user-determined amount of time before the RCX has the motors move simultaneously. Otherwise, students can choose to await until the sensor is depressed before directing the motors to move in sync once again.

9.7. Post-construction activities

Programming is one of the means by which children can come to develop a self-realization of original ideas and other educationally significant discoveries. Manipulating the robot is the other means. Students bumpers will be too small, while others will be too large. The touch sensor may not be sensitive enough, meaning a larger force needs to be applied to the bumper in order for the sensor to work. That means increasing the speed. Inlaid there are three concepts or ideas alone: force, speed, and sensitivity. It is at the discretion of the teacher as to which original ideas are paramount to others. Whichever ideas the teacher chooses, education standards often provide appropriate standards that students should achieve. Each team member should have an awareness of the original ideas and the means of assessing the students understanding of the ideas. In the case of the Gear Bot, once the robot completes a controlled turn, the idea of rotational velocity is deemed to be understood. To be clear, a controlled turn is one in which the robot turns until a constraint, either time or depression or release of a touch sensor, occurs. In other words, the robot shouldn't stop turning simply because there is a physical barrier. While the student may not understand the terminology, if they have a physical understanding of the idea, then the idea has been successfully conveyed.

10. APPENDIX B: MONORAIL

10.1. Pre-Construction Activities

The monorail is an excellent example of the concept of equilibrium and the need to balance forces. The monorail car does not move along the ground, but rather, along an approximately one inch rail elevated six inches in the air. It is imperative that the car's weight be balanced around its neutral axis. Students can gain an understanding of this phenomenon by walking along a beam suspended off the floor just a few inches. Teachers should take a 2 X 4 inch wooden beam and simply support its ends atop some textbooks. As long as students' center of gravity is maintained over the beam, the person will be able to move along the beam. Once a student's weight is not centered over the beam, they will have a difficult time trying to maintain their balance.

10.2. Construction Activities

The construction of the monorail is interesting in that there are two major projects to complete before the intended ideas are even capable of being tested. First a balanced car is created, and then sections of rail are built. Each rail is constructed using beams, connector pegs, and plates. The columns, themselves constructed using beams, are simply pinned to a base, and fixed aside the rail. Following the LEGO-supplied directions, the columns are spaced approximately one foot, center to center. Once the rail, which measures approximately 30 inches long, is centered about the columns, ten-inch overhangs remain. The students should be required to build a minimum of two sections of rail. When piecing the sections together, the result will be alternating bays of

12 and 18 inches. It has been the experience of the Bancroft Team that the LEGO-designed monorail car is too heavy to be supported in that section. As the car approaches the mid-point of the 18-inch bay, the rail either snaps or develops too much flexure for the car to move. It is at this time that one of the original ideas presents itself.

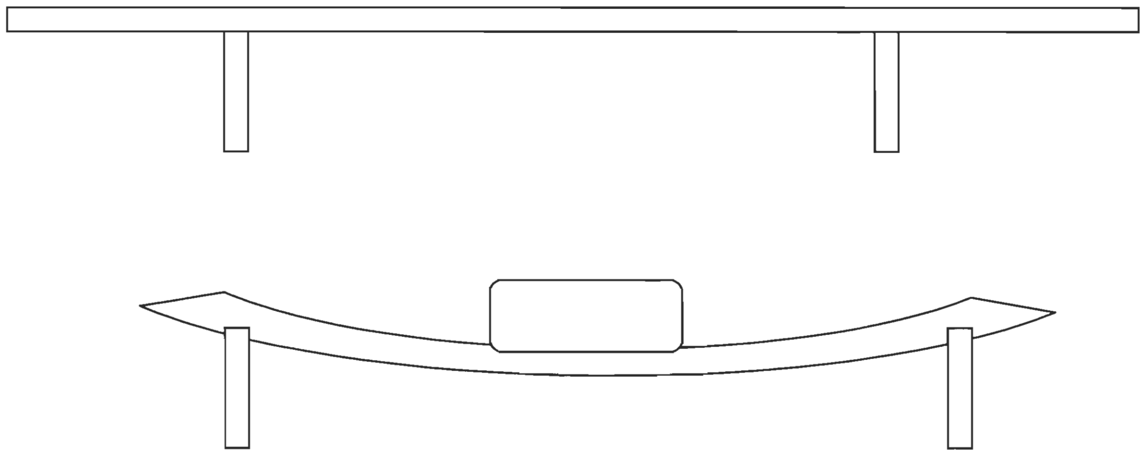


Figure 7. Resultant deflection of rail

The force of gravity acts on all objects upon or within a certain radius of the earth's surface. The magnitude of the force of gravity on an object, $\mathbf{F}_G$, is commonly referred to as its weight.

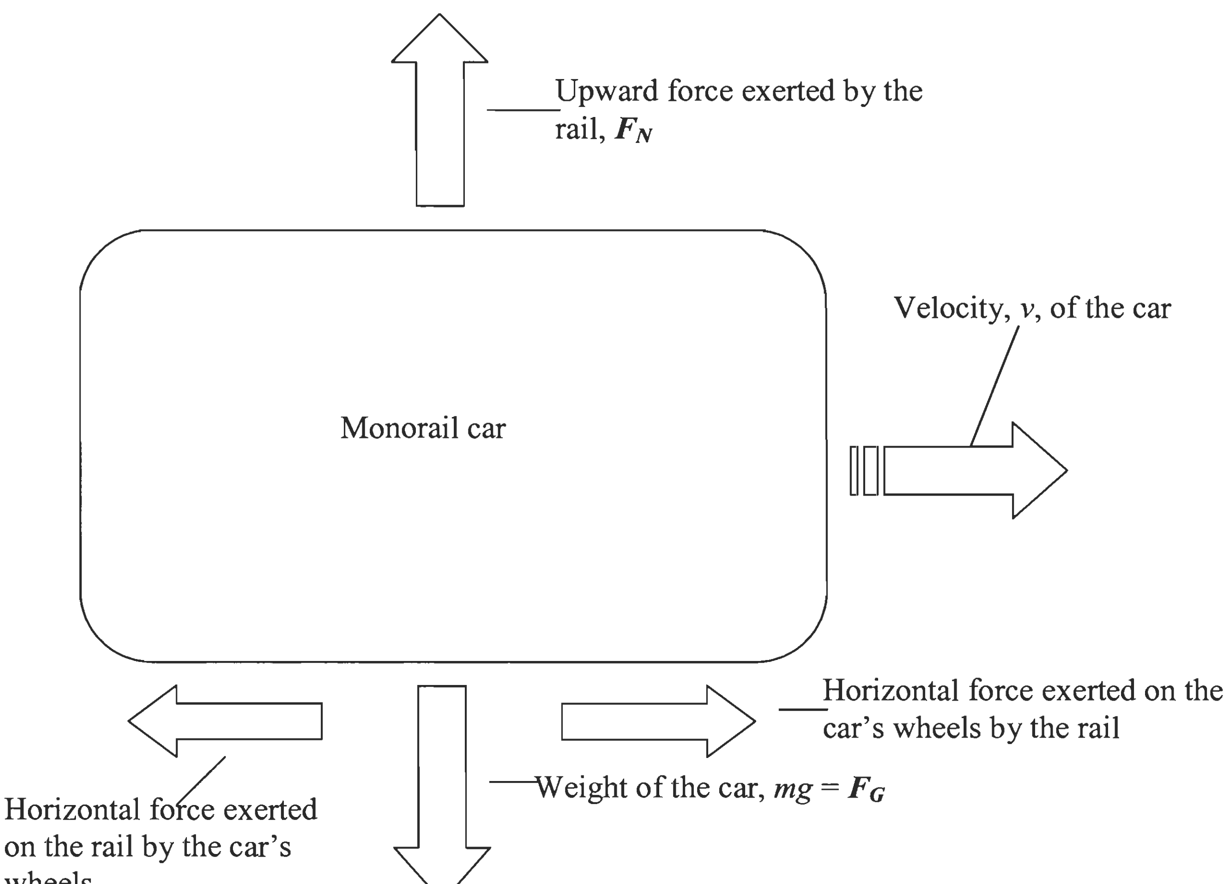
$$F_G = mg$$

Objects on the ground experience the force of gravity (it's what keeps us grounded). However, the earth is exerting an equal and opposite force back on our the object. This keeps objects from falling into the center of the earth. As long as the forces acting in one direction sum to zero, the object will not move in that direction. This is called Newton's third law of motion.

Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

When the summation of forces in any direction does not sum to zero, the resultant force will indicate the direction of travel. In the case of the monorail car, the resultant of the horizontal forces will cause the car to move forward. This is an example of Newton's second law of motion:

The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the direction of the net force acting on the object.



As an equation, Newton's second law can be written

$$a = \frac{\sum F}{m}$$

Put another way, a force is an action capable of accelerating an object.

These are all ideas that are central to the monorail project. While it is not expected that students will leave the session with the terminology in tact, the physical acts which these terms define should be recognizable to the students. Students may develop a first-time self-realization of the idea using any process associated with the learning styles.

The car is balanced on the rail by a set of angled beams that straddle the rail. Two wheels, attached by axles to the frame, move the robot along the rail. The RCX sits atop the two-beam chassis, which makes up the central axis on which the robot is balanced.

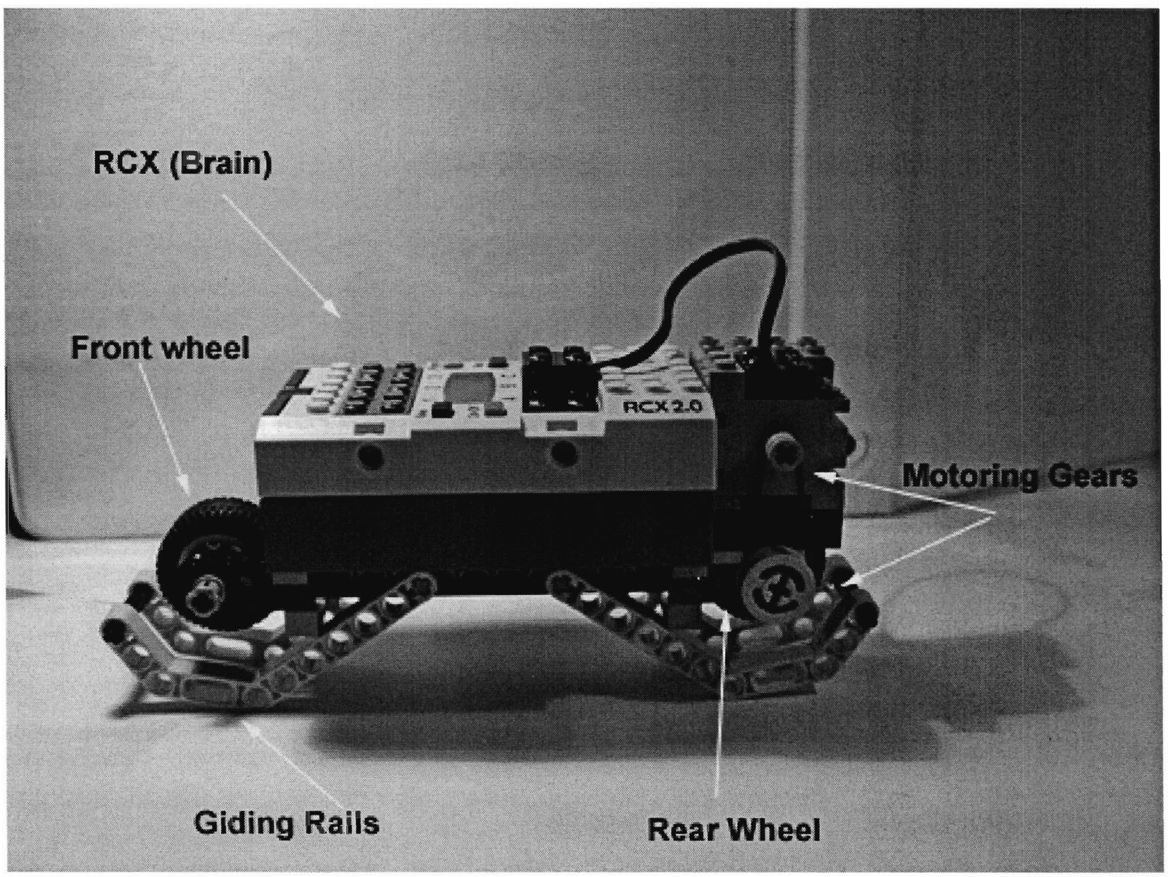


Figure 8. Monorail car

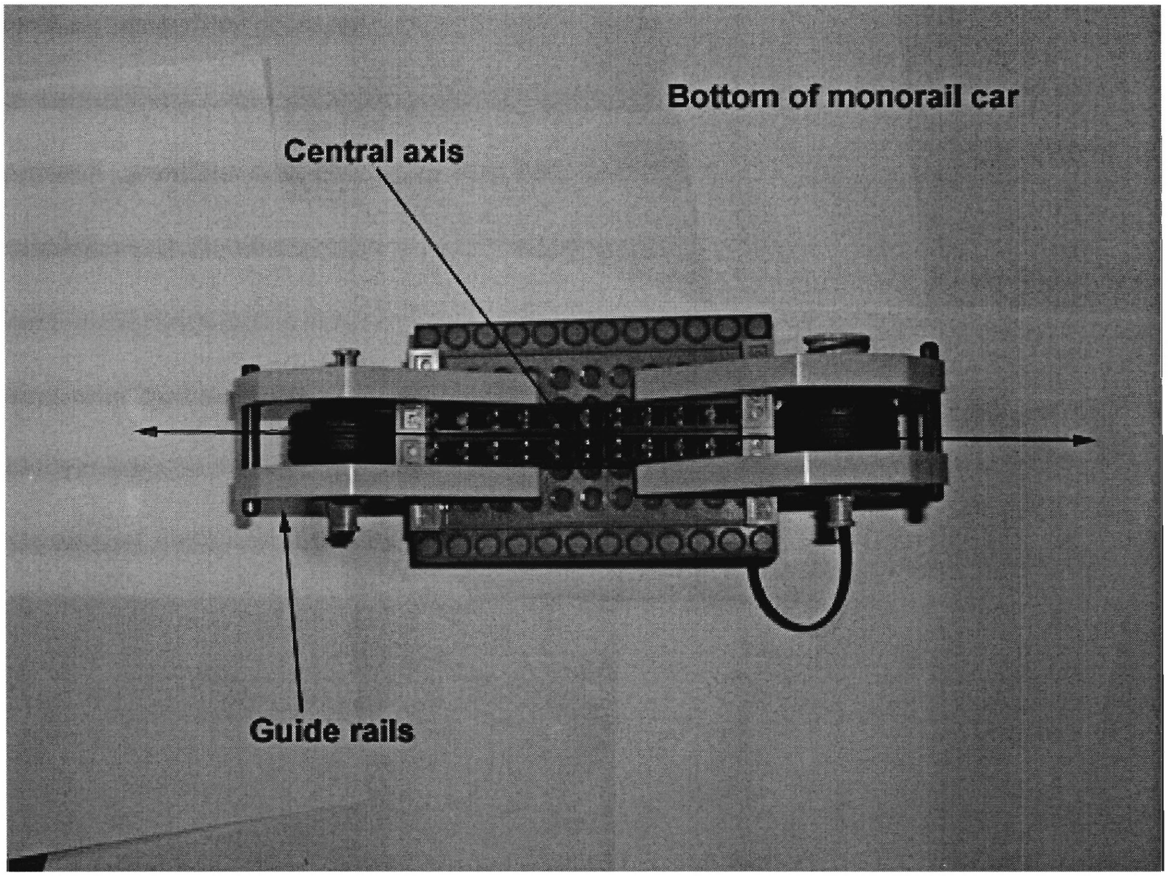


Figure 9. Underside of monorail car

10.3. Programming

Students who successfully built both the monorail car and at least two sections of rail programmed their robot to perform the following tasks.

- Move forward along a track
- Sense when the car has reached the loading station
- Await for passengers to board the train
- Move either forwards to another station or backward to the original station.
- Sense when the car has reached the second station
    - Sensation must be in a different manner than the first
- Allow time for passengers to disembark the train.

This program makes use of both touch and light sensors. For younger students participating in the monorail jr. project, the order of interaction of the sensors was told to them ahead of time. The older students were not told what sensor their robot would first receive input from. This forced them to create two separate if-then loops in Investigator. This program would essentially tell the robot: if light is sensed, stop and back up until the touch sensor is depressed. If the robot first senses an input through its touch sensor, the next sensor to be assessed will be a light sensor. Both of these scenarios are possible. If the student has programmed the sensors in reverse, then they will lose control of their robot.

10.4. Post-Construction Activities

After construction, this activity is more stringent than those involving robots that move on the floor. Its mobility is limited. However, this allows for more time on abstract concepts that are not immediately known to the untrained mind. Programming receives more attention, and the failures have more dire consequences. If the robot neglects to sense or respond to an input from a senor, it can fall off the either the end of the track or result in the car causing too much flexure in the rail. In any event, the car would crash to the floor and require that the student rebuild. Precision building, keen observation, and successful programming of the input sensors are factors that will help a student succeed with this project.

11. APPENDIX C: THE ELEVATOR

The elevator project was completed once students had an understanding of the pieces of LEGO Mindstorms and how they fit together. Unlike almost all the experiment before it, the visual instructions were three-dimensional. In addition, the visual learners who had grown accustomed to step-by-step instructions only had a completed elevator as a reference. Students had to use other learning styles such as communication amongst themselves, reflections on how elevators work, hearing verbal instructions from the team, and being able to massage a previously completed elevator. This project had many original ideas that children could discover.

Like all constructions, there was a goal given to the students before construction began. The goal was to construct a three-story building that housed an elevator capable of stopping on all three floors. A person on one floor could select another floor that he or she would like to travel to. The elevator would transport them to their desired floor without incident. The construction, in this case, was where much of the manipulation that leads to self-discovery was intended to take place.

11.1. Pre-construction activities

Certain ideas were unique to this project. The use of pulleys to provide mechanical advantage was a concept reserved for upper-grades because the team felt that it was important to utilize free-body diagrams to demonstrate the reasoning that led to an object being lifted with less force. Newton's second law was utilized in describing the mechanical advantage that pulleys demonstrate. Short of constructing a pulley system in the classroom, it is difficult to mimic the action that occurs.

By having the students construct the elevator shaft by themselves they learned a valuable lesson in levers, lever arms, and torque. All pre-construction exercises are meant to physically and mentally demonstrate the original idea to the students in a symbolic form that they can relate to. This is an opportunity for the teacher to relate an idea or topic to something that the students understand. To demonstrate the idea of a lever, and a lever arm, students had to consider that their feet were glued to the floor. They had to imagine that all the muscles in their bodies shriveled up and were useless. Students were asked what would happen. Naturally, students realized that they would fall down. Next students were told that their muscles were stiff as a board, and they could not move their bodies on their own, but the slightest bump would cause them to fall while their feet were still glued to the floor. Essentially, the team was asking the student to think of their ankles as fulcrums, or points of rotation. They would rotate in only one direction, and about that point. Students were asked how they could be kept from having the wind blow them over. The desired response was to have somebody hold them up.

11.2. Construction activities

The four columns of the elevator shaft created by the instructional team used the idea of a lever and lever arm. The upright columns were fixed to a base by a pin connection. As the building rose in height, lateral forces due primarily to the uneven construction of the shaft caused a moment. The lever arm is the perpendicular distance from the axis of rotation (the pin) to the line of action of the force. Regardless of how small the lever arm is any force perpendicular to such an arm will result in rotation about the axis. The product of the force times the lever arm is called *torque*. To contest this torque, lateral and diagonal bracing was used to prevent a resultant force from occurring.

Attached to one side of the building were diagonally vertical beams that prevented rotation about any axis, and in turn, made the connection a stiff one. The idea of rotation about an axis, torque, and the structural failure that it can cause when incorrectly placed was a lesson that many students learned only after their shaky first-time shafts fell and broke. Bracing the structures correctly is important, because the structures they are building will have to hold weight at some point.

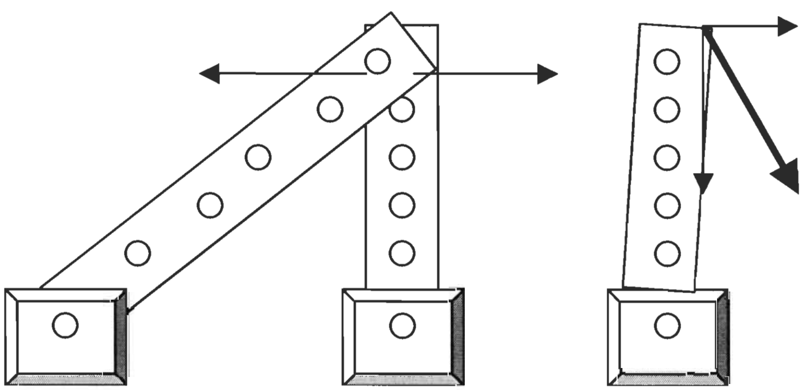


Figure 10. Force diagram for supported and unsupported column

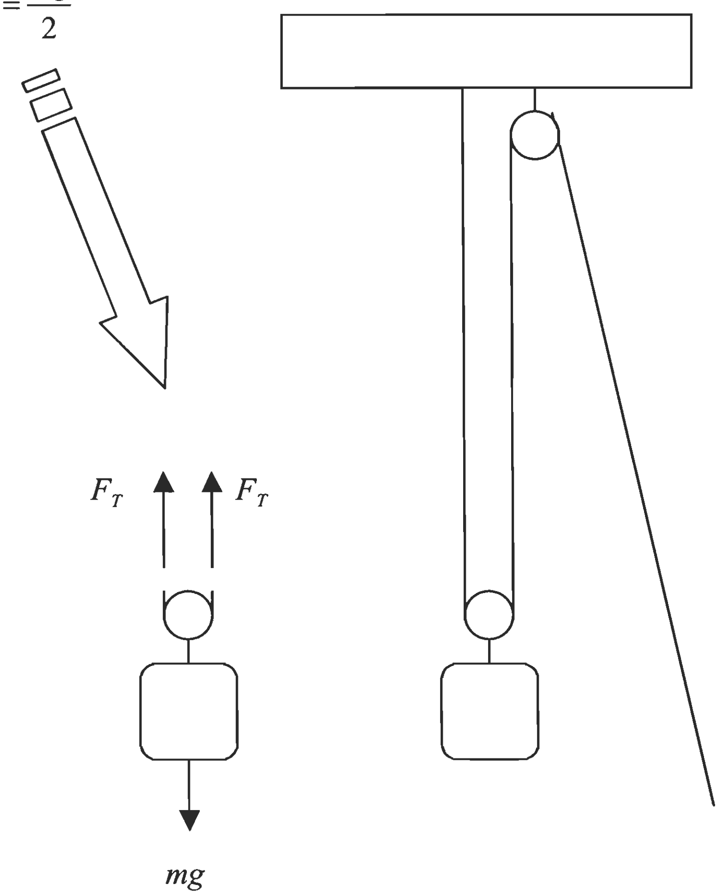
Once the structure was built, students had to engineer a way to move the car up and down the shaft. The solution demonstrated in the model should show a pulley system, shown on the next page. Using this type of a pulley, the mechanical advantage offered is double what would have to be exerted under normal. The weight of the car, ***mg*** acts in an opposite direction as the tension in the looped rope moving through the pulley. Using Newton's second law

$$2F_T - mg = ma$$

In order to move the car at a constant velocity, negating acceleration, the tension in the string, and therefore the force that must be applied by the motor and axles is $F_T = mg/2$.

$$2F_T - mg = ma$$

$$F_T = \frac{mg}{2}$$



Construction of the elevator shaft should be able to accompany this construction. Students may require assistance in duplicating this construction, because of the careful detail that must be taken when attaching the string to the axle on the motor and directly atop the elevator shaft.

11.3. Post-construction activities

This is the only project on the Bancroft curriculum during which the RCX does not move along with the robot. There are many different tasks that the elevator can perform. One simple program is as follows.

1. Move up
2. Sense upper-most level has been reached using a touch sensor
3. Reverse motor direction
4. Sense lowest-most level has been reached using a touch sensor

This program uses a touch sensor as the only constraint. The elevator is incapable of stopping on any floor, and passengers are given no time to embark or disembark. Whereas the monorail made use of both time and light constraints, the elevator programming makes use of both time and touch constraints. A figure of the one of the more advanced programs is demonstrated in Figure. Depending on the complexity that the teacher wishes to have with the students, the program may be modified to include time for the passengers to get on and leave the elevator car.

1. Start program
2. Stop motor for XX seconds
3. Move up
4. Sense upper-most level has been reached using a touch sensor
5. Stop motor for XX seconds
6. Reverse motor direction
7. Sense lowest-most level has been reached using a touch sensor
8. Stop motor for XX seconds

9. Repeat steps 3-8 through the use of a loop

A more vigorous and abstract program is demonstrated below. Using Investigator, the student can program the RCX with three touch sensors that act similarly to the buttons for floors in the cars inside a real elevator. Once labeled, an elevator patron can select a floor he or she would like to go to. The elevator will move to that floor, and await for the patron to get back on the elevator. At that point in time the patron can select the floor he or she wishes to disembark on, and the elevator will take them there using a time constraint. This process works for elevators in the LEGO world, but it may seem impractical for the real world use. There are variations, therefore, that the teachers or students can suggest.

The elevator is limited by only having three possible inputs per RCX. Teachers or students may suggest that the elevator return to the bottom floor after a patron disembarks so that other people may use it. In this case, after a delay at the floors, the motors simply reverse direction for the same amount of time that they ascended.

Students may consider using two RCXs and having them communicate to each other. This would allow for the use of up to six sensors; one sensor for the user to indicate their desired floor, and three other sensors to tell the car when it has reached the desired level. This program would be an interesting project for an advanced ROBOLAB Investigator user to investigate and build.