

Piaget and Engineering Education

Lawrence J. Genalo, Denise A. Schmidt, Melanie Schiltz
Iowa State University

Abstract

Thomas Edison was a noted engineer while Jean Piaget made his fame in children's educational psychology. Piaget's "cognitive constructivism" has been adopted in many early childhood programs, but it also applies to engineering education and its "hands-on" approach, especially in laboratories and project-based courses. The direction of education dramatically shifted when Jean Piaget developed a child-centered developmental learning theory. According to his theory, children construct knowledge about their world through their active involvement in experiences that are meaningful for them in order to provide an ideal learning environment. A Piagetian classroom is filled with authentic activities designed to challenge students so they can construct knowledge at their own developmental pace.

Creating constructivist learning environments where students construct their own meaning is not an easy task. Learners need opportunities to learn in a constructivist manner to effectively connect new ideas to existing schema. Educators must empower students to ask their own questions and seek their own answers, experience the world's richness, and challenge them to understand the world's complexities. Classroom instruction is frequently centered on delivering the content to students instead of facilitating student inquiry during the learning process. Although many of the principles of constructivism offer promise in the development of successful learning environments, practical applications are often hard to incorporate into the common constraints of the school environment.¹

With the recent emphasis on "learner-centered" education in engineering education, a deeper understanding and application of Piaget's work is in order. The purpose of this paper is to present a model of an engineering/education collaborative program that is built on Piagetian principles and attempts to outreach to K-12 students to build their enthusiasm for engineering and science. Thus, this paper will describe how Piaget's work was continued by Seymour Papert who then introduced the idea of "constructionism" and how that concept applies to engineering education in the Toying With TechnologySM Program at Iowa State University (<http://www.eng.iastate.edu/twt>). A comparison of Piaget's pedagogy and Edison's work will demonstrate why this pedagogy has application in engineering.

Introduction

What could an inventor like Thomas Edison and a child psychologist like Jean Piaget possibly have in common? Edison spent his life inventing things which he felt needed to be improved or would make the lives of people a bit easier. Jean Piaget devoted his life to studying how a child

develops mentally, emotionally, and physically. Piaget developed a theory of how a child learns, yet when you look at Edison and the process that he used when inventing it becomes clear that the two are very similar.

If one examines the processes used by most engineers in research and development, many aspects of Piaget's work can be found. Entering an engineering laboratory class today one would see many hands-on activities and projects targeted at engaging students to construct their own knowledge. By comparing Piaget's pedagogy and Edison's work one can see that the constructivist approach applies to the engineering field and engineering education.

Piaget's Cognitive Constructivist Approach to Learning

Jean Piaget devoted his life, from the time of adolescence, to the study of how children learn and develop. He had a father who believed in science and nothing but proven scientific facts; he had a mother who believed solely in religion and the truths associated with it. Piaget believed that all adolescents must create a balance between faith and reason.² It was this belief of equilibrium that led to the start of his research in the area of developmental psychology.

Piaget developed an influential model of child development and learning. This theory revolutionized teaching methods and changed the way that developing children are viewed. According to Piaget, as a child develops physically, mentally, and emotionally he or she connects new knowledge into a web, or schemes, of pre-existing knowledge.³ A child's development is influenced by how he or she understands and responds to physical experiences encountered in the environment. As the child develops over time these schemas become increasingly complex.

Piaget identified four stages that all children progress through developmentally; for the purposes of this paper we will be focusing primarily on the final two stages. However, a brief overview of the first two stages will help with understanding. Piaget's first stage, sensorimotor, occurs between birth and approximately age two. During this stage a child begins to build a picture of reality through the physical interactions they have with others. The second stage, preoperational, takes place between the ages of two and seven. In this stage a child has not yet developed the ability to think abstractly and needs to remain in concrete physical situations.

The third stage of development, concrete operations (ages seven to eleven), is one we would like to closely examine. At this point a child begins to conceptualize and think abstractly. A child starts making logical connections to things they already understand. The schemas are becoming more complex and more intertwined. At this time of development, a child is beginning to realize that things can overlap and connect in more than one way.

Beginning at about the age of eleven and until around age fifteen, a child begins Piaget's final developmental stage of formal operations. Piaget believes that by the time a child has reached this developmental stage abstract thinking is fully in place. The cognitive structures of an adolescent have also reached those of an adult. Adolescents can now logically solve a problem without having concrete objects to help them and can make logical connections to existing schema more accurately.

Piaget believes that a child will only progress through these stages if they are allowed the freedom to construct their own schemes and connections to pre-existing knowledge. The experiences that a child receives must allow them the freedom to create their own connections. As a new concept is introduced the child will go through a period of confusion and unbalance. They may struggle with what they have discovered or even initially reject it. As they come back to the idea and begin to make connections to prior knowledge their concepts will be altered. As children make more and more connections between the new things they discover and their pre-existing knowledge, there is an ongoing process of creating equilibrium with the known and the unknown. It is this shifting between the known and unknown that leads to more accurate concepts of reality and more complex schemas.

Some educational researchers have challenged Piaget's theory stating that learning does not develop in sequential stages of cognitive development. Seymour Papert, the creator of LOGO and supporter of Piaget, has observed that when children use technology they seem to progress through these stages of development, but do so in different ways.

Papert and Constructionism

Seymour Papert, co-founder of MIT's Artificial Intelligence and Media Labs and professor of Media Technology at MIT, was greatly influenced by Jean Piaget and his theory of children's intellectual development. Before beginning his tenure at MIT, Papert spent four years actually working with Piaget in a Geneva research center studying how children think. Papert was an educational 'visionary' on his ideas about how we might think about how children learn. He believed that providing children with opportunities to 'play with a problem' would enhance their intellectual abilities and processes to solve a problem.⁴ Educational experiences such as these would illustrate noted philosophical principles such as child-centered and constructivist approaches to learning.

Papert purports that for children to experience new types of learning, education needs a very different kind of theory of learning. His criticism of learning in today's schools is motivated by the idea that a child becomes the passive recipient of knowledge. He believes that best learning takes place when the learner takes charge, a concept closely aligned with Piaget's theory of intellectual development. Papert believes that "every act of teaching deprives the child an opportunity for discovery" p. 139.⁴ Hence, Papert developed an educational philosophy he refers to as constructionism.

According to Papert, a main feature of constructionism is the idea of mental construction. It shares a constructivist view of learning - building knowledge structures. Papert admits there is really no easy definition of constructionism because it is multifaceted; it's just a sense of knowing that everything can be understood by being constructed.⁵ Clearly, his research studies with children document the creation of active learning environments where they use LEGO construction kits and LOGO microworlds to build models that are solutions to problems. These types of learning experiences offer children real opportunities to actively find solutions to concrete problems.

Both, Papert and Piaget believe that students need stimulating learning environments where they can explore and then discover solutions to problems posed in these environments. Thomas Edison, well-known engineer and inventor, represents an individual who approached learning as the process of discovering and rediscovering the solution to a problem.

Thomas Edison: A Constructivist Learner

“In trying to perfect a thing, I sometimes run straight up against a granite wall a hundred feet high. If, after trying and trying and trying again, I can’t get over it, I turn to something else. Then, someday, it may be months or it may be years later, something is discovered either by myself or someone else, or something happens in some part of the world, which I recognize may help me scale at least part of that wall. I never allow myself to become discouraged under any circumstance.”⁶

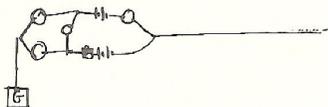
This quote is an excerpt from Thomas Edison’s autobiography entitled, *The Diary and Sundry Observations of Thomas Alva Edison*. It embodies the spirit of how Edison invented and worked. It also captures the essence of the developmental process of a child that Piaget describes.

Thomas Edison was deaf. He did not view this as a disability, but rather found it a blessing. Because Edison could not hear, he spent a lot of time reading. He started reading as an adolescent and it was this fascination with books that helped inspire the inventor within him. He educated himself by reading library books and he gained a rich and deep background on a variety of topics. Edison also spent a lot of time reading newspapers. In his diary, Edison admits reading five newspapers daily.⁷ He asserts that an idle mind is a dangerous thing because it leaves too much time for things like breaking laws and getting into trouble. It is evident that Edison was always expanding his knowledge base about a given topic through reading books and newspapers.

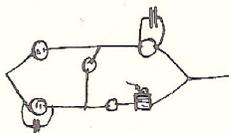
The illustrations shown in Figure 1 represent Edison’s thought processes and learning experiences while developing the automatic telegraphy.⁸ These illustrations provide some evidence that Edison’s approach to problem solving reflect thinking processes and knowledge acquisition that occur during Piaget’s developmental stage of formal operations. As Edison begins to construct his ideas about how this invention will ultimately work, the illustrations demonstrate how he assimilated his new ideas with his existing cognitive structures and then made adjustments in his understanding of how this invention would work.

Clearly, Piaget’s work supports Edison’s approach of knowledge acquisition and mental development. The more new things an individual incorporates into their existing schemas, the more knowledge the individual will have to draw from. It is this never ending process of learning on one’s own accord that fascinated Piaget.

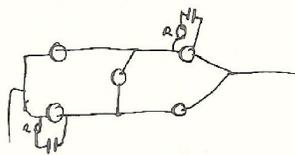
See if the inductive effect of the magnet is affected by the batteries, balanced in the bridge thus



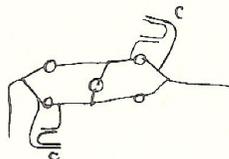
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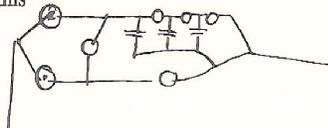
Try with magnet & without, see what condensers will do. Then thus to get longer charge



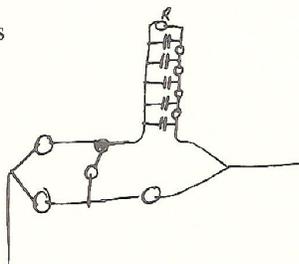
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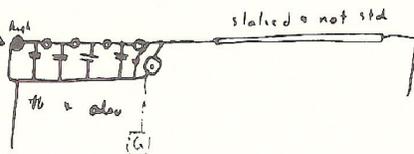


Figure 1: Illustrations representing Edison's approach to problem solving and invention.⁸ Permission for the use of the figure granted by the Edison Papers Project at Rutgers University

Piaget Meets Engineering Education

Thomas Edison was an engineer and he worked as engineers work today. Engineers today start out with a design and a concept. They make prototypes and test them. When something goes wrong they take what worked and they change what did not. Engineers begin with a base knowledge and they learn new things as they progress. They change their approaches to problem solving as needed and they keep making revisions until they have a final product that works. That final product may look very similar to the engineer's original design or it may be changed considerably.

Obviously, Edison approached problem solving using similar methods and processes. He understood what he wanted to ultimately accomplish and he continued to work toward that goal until he reached it. When Edison discovered that one of his ideas wouldn't work, he would alter his schema and try something new. Sketches found in his work journals document the many changes Edison would make to the design prior to the final product and patent. Even after applying for a patent Edison would continue to make improvements on the design. In fact, the many changes and improvements he made to the telegraph system are well documented.

The combination of Piaget's theory of learning development and Edison's work are applied widely throughout today's education of future engineers. In most laboratory classes, students are challenged to find solutions to authentic problems using a more hands-on or student centered approach to problem solving. By contrast, students in the lecture setting are usually given information they will need as a basis for what they will learn in the laboratory setting. For example, in a robotics programming class students learn the actual language the robot uses in the lecture setting. Sample programs are shared with students to illustrate how the language works. Then, when entering the laboratory setting, students are given a specific learning task that they are to complete using the programming language. There may be more than one way to write the program to accomplish the task, but students are not told which method to use. The program the student writes is sent to the robot and the student observes the program's steps in execution. In a recursive manner, revisions are made to the program until the task is completed correctly.

This type of laboratory setting draws heavily on Piaget's ways of thinking. Piaget would consider what students learn in the lecture about the programming language as new knowledge. The language, as it is explained in class, is integrated into each student's schema in a slightly different way. As the students enter the laboratory setting this new knowledge becomes the existing knowledge and the application of the programming language becomes new knowledge that now must be integrated with the existing schema. For most students this will mean only minor alterations to the schema that was developed in lecture, while for others it will require major changes in their existing schema and conceptualization.

As students program the robot to complete the assigned task, they are testing a hypothesis of how they think the robot will react. Then, upon testing, the students discover that the robot did not do what they thought that it would. At this point the equilibrium is unbalanced in the student's mind. He or she will have to revisit the program, change parts of their understanding, develop

new links, and gain a more complex and accurate picture of the program and the programming language.

The laboratory setting described here is exactly the way Edison worked. He used his knowledge and problem solving abilities to accomplish a goal. Edison would try one thing and if it didn't work he would try something else. After each new idea Edison's schema was altered as he integrated new knowledge into his existing knowledge base; a process Piaget call assimilation. Edison was working just as an engineering student in a laboratory class might work. He was applying his understanding of knowledge to new situations, while elevating that knowledge to new levels of understanding. He was experimenting with the known to discover the unknown.

Toying With TechnologySM Program Meets Piaget

The Toying With TechnologySM program at Iowa State University is one that embodies the constructivist views of Piaget. It is a project-based, hands-on learning course aimed at teaching education majors some of the many ways that they can incorporate engineering into their curriculum. The basis of the course is hands-on laboratory experiences designed around simple systems constructed out of LEGOs. Other engineering projects, not involving LEGOs, are also used in the class. The program functions like other projects around the nation such as the Learning by Design Program at Georgia Tech⁹, but has a stronger emphasis on engineering rather than science.

One activity done each semester is the Egg Drop. Students must design, build, and program a machine that will transport an egg from a table down to the floor without breaking the egg. Students are given one LEGO Robotics Kit and a string to build their machine. No restrictions are placed on their design aside from the fact that it must be completed within a given time frame. This loosely phrased design problem allows the students freedom to construct their own knowledge of the problem solving strategies needed. In this way they not only construct their engineering device (like Edison), but also construct new knowledge and weave it together with their existing knowledge (like Piagetians). This is the essence of Papert's constructionism and it focuses on the third (concrete operations) and fourth (formal operations) stages in a Piagetian cycle.

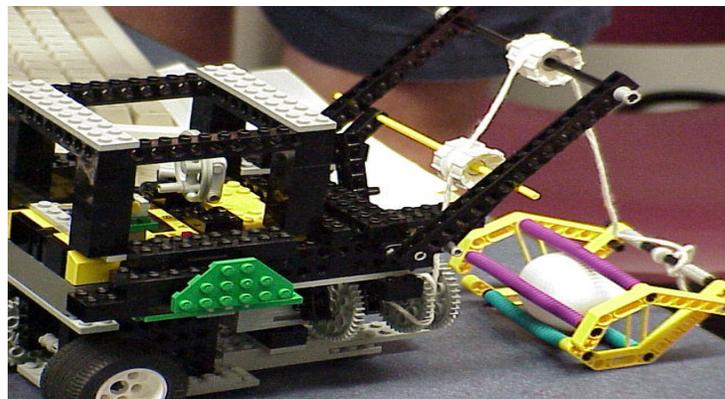


Figure 2. An Egg Drop Solution

Another project involves the design, construction, and testing of a boat to hold weight in an on-board cup. The students must study Archimedes' principles while designing their boats and predict the amount of weight their boat will hold. This project once again embodies the constructionist pedagogical viewpoint.

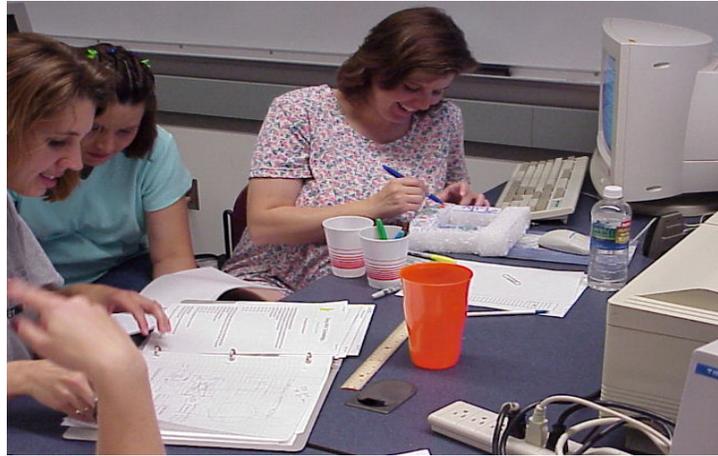


Figure 3. Inservice Teachers in the Summer Graduate Class Working on their Boat Design

The course also covers other engineering principles and gives students ideas about how to teach those principles. For example, a teacher could teach about chemical reactions by making homemade ice cream. When taught correctly this lesson is a wonderful, hands-on activity for students because they get to see and feel the actual chemical changes as they occur. Another hands-on activity done in *Toying With Technology*SM is building towers or bridges made from raw spaghetti and gum drops. Students work in partners to create either the tallest free-standing tower or the strongest bridge. They are given no restrictions on how to build the structures. Then each structure is tested and the different designs are discussed. With the towers, for example, the groups who choose triangular shapes usually end up the tallest. With subtle hints students usually discover this principle by themselves.

The activities within the basic structure of the course seem to change from semester to semester. New ideas are tried and old ideas are brought back or altered. One thing remains constant; the course is hands-on and constructivist in nature. Course assistants we are instructed not to tell students what a problem is or how to fix it. Hints can be given but not the answer. Students are supposed to figure out the problem themselves or with their partners. When this problem-solving occurs new schemas develop and learning truly takes place. As the semester progresses the students become more willing to try something they are not sure will work. They become more comfortable with the program language but the schema is always changing, they are always discovering new things about how it works and integrating that into their reality.

Conclusion

By comparing Piaget's pedagogy and Edison's work one can see that there are many more similarities than differences between their ideas and approaches to learning. Piaget studied how the child's mind develops and forever impacted the way we teach children. Edison invented

things that made our lives a bit easier and changed the way we live. Edison was, indeed, a model of Piaget's constructivist model of learning.

Today Piaget's theory can still be seen in the modern engineer. Whether one is looking in the workforce or the college setting where engineers are being trained, Piaget's model of development and learning is prevalent. It is the structure around which many courses, *Toying With Technology*SM being one of many examples, are successfully developed. Indeed, creating environments that promote constructivist or constructionist approaches to learning can help foster students' critical thinking and problem solving skills when finding solutions to problems. Piaget's cognitive constructivist theory as embodied in Edison's work is still very much alive in engineering education today. It has fueled the creation of the *Toying With Technology*SM Program and forms a link between the colleges of engineering and education at Iowa State University.

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LAWRENCE J. GENALO

is Professor and Assistant Chair of the Department of Materials Science and Engineering at Iowa State University. He received a Ph. D. in Applied Mathematics with Systems Engineering emphasis in 1977, served as Chair for Freshman Programs and DELOS Divisions, and runs the *Toying With Technology*SM Program at Iowa State.

DENISE A. SCHMIDT

is the Associate Director of the Center for Technology in Learning and Teaching within the Department of Curriculum and Instruction at Iowa State University. Her research interests include technology use and integration in PreK-12 classrooms and technology in teacher education.

MELANIE SCHILTZ

is a senior in elementary education from Manilla, Iowa. She works in the Toying With TechnologySM Laboratory as an undergraduate teaching/laboratory assistant. Her interests include integrating engineering concepts into the elementary education curriculum.