Inquiry-Based Training Model and the Design of E-Learning Environments

Bijan B Gillani
California State University, East Bay
Hayward, California, USA

Bijan.Gillani@csueastbay.edu

Abstract

Cognitive developmental theories attempt to explain cognitive activities that contribute to students' intellectual development and their capacity to learn and solve problems. Cognitive developmental research has had a great impact on the constructivism movement in education and educational technology. In order to appreciate how cognitive developmental theories have contributed to the design, process and development of constructive e-learning environments, The author will first present Piaget's cognitive theory and derive an inquiry-training model from it that will support a constructivist approach to teaching and learning. Second, an example developed by the author and his graduate students will be presented that uses the Web as an appropriate instructional delivery medium to apply Piaget's cognitive theory to create e-learning environments. The result is a collection of simple, uniform, and effective inquiry-training math web sites for elementary and middle school students. The information presented can be applied to other subject areas as well.

Keywords: Cognitive theories, constructive, e-learning, inquiry training, Web.

Introduction

The explosive growth of the Internet and the dramatic advances in the design and development of online technological tools in recent years have revolutionized the way students and teachers view technology in education. These technological advances have made it possible to produce educational materials and transmit them over the Web. In parallel to these technological advances, the field of instructional design has made phenomenal contributions to curriculum planning. A synergy of these two fields would enable educators to produce effective electronic educational materials.

Unfortunately, a great majority of e-learning sites that use online tools lack appropriate theoretical foundations for curriculum content organization. These sites, all designed by highly intelligent and well-intentioned educators, use online technologies without any regard for application of pedagogy to the design of courses. The result is shallow curriculum where, at best, online technologies have been used to cover the tip of teaching and learning, leaving little time and effort for the students to delve into deeper understanding of curriculum and problem solving. There is a fundamental need for pedagogical approaches to design e-learning environments whose foundations are supported by effective theoretical framework.

One of the most effective approaches to developing appropriate pedagogical models for the design of e-learning is to understand how cognitive development occurs naturally. Cognitive development theories attempt to explain cognitive activities that contribute to the learners' intellectual development and their capacity to solve problems. Once we understand how cognition develops, we can derive a pedagogical model from it and then design effective e-learning environments that are responsive to how students learn naturally. In what follows, Piaget's cognitive theory will be discussed and an inquiry- training model will be derived from it. Then I will describe the design of an e-learning environment that is based on Piaget's model and is adaptive to the cognitive needs of students.

Cognitive Developmental Theory

Piaget

Piaget (1952) argued that children must continually reconstruct their own knowledge through a process of active reflection upon objects and events until they eventually achieve an adult perspective. To have a better appreciation of this process, it is essential to understand four other concepts that Piaget proposed. These concepts are schema, assimilation, accommodation, and equilibrium.

Schema

Piaget (1952) used the word schema to represent a mental structure that adapts to environmental patterns. In other words, schemata are intellectual structures, in terms of "neuron assemblies," that organize perceived events and group them according to common patterns. A number of researchers (Anderson & Pearson, 1984; Piaget, 1952) have posited that schemata are the building blocks of intellectual development. During cognitive development, children's schemata are constantly restructured as they encounter new patterns in their learning experiences.

Schema is not limited to concepts, objects, data, and their relationships. There are also procedural schemata (Anderson & Pearson, 1984), which are the ways of processing information. For example, students who have acquired the basics of mathematics, such as adding, multiplying, dividing, and subtracting, have internalized the concept schemata about these mathematical operations. However, as the students grow, they gain new abilities to solve problems that are related to mathematical concepts. The ability to solve problems is a procedural schema. Both concept and procedural schemata are constantly restructured as new learning environments are introduced to the learner.

Assimilation, Accommodation, and Equilibrium

One of the most fundamental questions about schemata is how are they restructured when new data or patterns are discovered in the environment? Piaget was a biologist by academic training. He was very comfortable with the concept of biological adaptation to environmental stimuli. For example, from a biological point of view the human body is structured to be constantly in a state of equilibrium in regard to its temperature. When the body temperature is raised by a few degrees during exercise, the entire system goes into a state of disequilibrium. The feedback mechanism senses such a state of disequilibrium and internally responds by producing sweat and sending more blood near the skin to cool the body down; thus, restoring a state of equilibrium for the body.

Piaget used the same concept of biological equilibrium-disequilibrium states to explain the causes of cognitive restructuring in response to new learning experiences. For example, when students encounter a new learning environment, a state of disequilibrium is created within their brains that must be internally managed. In other words, the new learning environment has placed the brain in a state of disequilibrium. In order for the brain to get back to the state of equilibrium, the learner has to add, modify, or restructure his or her schemata to account for the new situation. The internal mental mechanism or processes that are responsible for the restructuring of schemata so that the brain can get back to an equilibrium state is called assimilation and accommodation. (Piaget, 1952, 1964)

Assimilation is the cognitive process by means of which people integrate new patterns, data, or processes into their existing schemata. Piaget argued that, as learners assimilate input from the environment, the new information is not simply stored in the mind like information in files in a filing cabinet. Rather new information is integrated and interrelated with the knowledge structure that already exists in the mind of the person. "Every schema is coordinated with other schemata and itself constitutes a totality with differentiation parts." (Piaget, 1952. P.7)

For example in teaching geometry, when a pentagon is introduced to children, the salient features of this geometric shape such as sides and angles are not simply memorized. Rather, it is contrasted and integrated with what is already known about other geometric shapes like rectangles, triangles and squares. In other words, the schemata for a pentagon includes, in addition to its shape, sides, and angles, such related concepts as how its shape compares with other geometric shapes, how its angles compare with other geometric shapes, or how its area and perimeter differ from other geometric shapes. Learning in this manner of relating prior knowledge to new information is said to be meaningful because new schemata in the child's mental capacity have been formed.

Theoretically, assimilation does not result in changes or restructuring of the schemata. Rather assimilation is the process of placing new information into existing schemata. Assimilation can be compared to the air that you put into a balloon. As you put more air in the balloon, it gets bigger, but the shape of the balloon does not change. The actual change or restructuring of the schemata occurs in the accommodation process.

The change that occurs in the mental structure of schemata is referred to as accommodation by Piaget (1952). Upon facing new learning environments, sometimes the learner's schemata cannot assimilate the new information because the patterns of the new stimuli do not approximate the structure of the existing schemata. In such cases one of two things can happen: The learner can create either new schemata or modify the existing schemata. In either case the structure of schemata is being changed so that it can accommodate new information. Therefore, accommodation is the creation of new schemata or modification of old schemata. In both of these cases the result is a change in the cognitive structure or the overall structure of schemata.

The process of cognitive development is the result of a series of related assimilations and accommodations. Conceptually, cognitive development and growth proceeds in this fashion at all levels of development from birth to adulthood (Piaget, 1964). However, because of biological maturation, major and distinctive cognitive development occurs over a lifetime. Piaget (1964) posited four major stages of cognitive development that occur over a lifetime. These stages are sequential and successive. According to Piaget, these stages are Sensorimotor (birth to 2 years old), Pre-Operational (2 to 7 years old), Concrete Operation (7 years to adolescence), and Formal Operation (adolescence to adult). The first three stages are not relevant to the purpose of this paper. Therefore, I shall only describe the Formal Operation development as it applies to students in grades 5-8 and higher

The Formal Operational stage of development generally begins in early adolescence and continues through adulthood. Formal reasoning is characterized by the ability to carry out mental activity using imagined and conditional actions and symbols that are divorced from their physical representation. Individuals at this stage are able to control variables systematically, test hypotheses, and generalize results to future occurrences. This stage, which continues to develop well into adulthood, is characterized by the ability to reason and solve problems. The Formal Operational stage is the most important stage in terms of application of Piaget's theory of cognitive development to the design of e-learning. Therefore, I will elaborate more on this stage here.

An influential scholar who has continued Piaget's work in the area of formal operation is Flavell (1985). He has provided a detailed discussion of three operations that young adults gradually acquire during the Formal Operation of their development. These operations are combinational reasoning, propositional reasoning and hypothetical-deductive reasoning.

Combinational reasoning refers to the ability of the adolescent to consider several different factors at the same time to solve a problem. This reasoning power provides learners with the ability to look at problems from an integrated approach. During earlier stages, children are not capable of integrating several viewpoints to solve problems. They can only deal with problems from one angle at a time. However, as adolescents mature into adulthood, they develop combinational reasoning which allows them to integrate several viewpoints to problem solving.

Propositional reasoning refers to the characteristic that young adolescents acquire to reason on the basis of assumption and proposition to solve problems. For example, if a child during the Concrete Operational stage were asked to assume that coal is white, the child would respond that coal is black and cannot be white. However, during the Formal Operation stage, the young adult acquires the capability of assumption and proposition to solve problems that would not have been solved during the Concrete Operational stage. This ability also extends to abstract thinking that is acquired during the Formal stage.

Hypothetical-deductive reasoning allows the young adolescent to consider different hypotheses in dealing with a problem. Consideration of different hypotheses also enables the young adolescent to gather data and test different hypotheses to come up with a possible solution.

To illustrate how adolescents follow hypothetical-deductive reasoning in everyday life, let's consider a simple example. Let's say that there is a young 15 year old girl who is going on her first date. In order to get ready for her date, the young lady goes into her room and gathers several different colored blouses and matching pants. She puts on a blouse and tries it with a pair of pants while looking at her choice in the mirror. She may reject this combination, and so she tries another blouse with different pants. After several tries she decides to wear the blue blouse with the black pants. This process of selection of what to wear is natural to most young people.

The instructional implication of such a procedure is significant. What the young lady has learned to do because of her recent development of hypothetical-deductive reasoning is the ability to hypothesize and test a situation. In order to solve the outfit problem, she first hypothesizes something about her taste in what looks good, and then she gathers information (her clothes). She then tests her hypotheses that some colors may go with others. She tests every one of her choices in color. She either accepts or rejects her choices. She makes a final decision, based on her original hypothesis and her testing, as to what looks good for her date. The final selection is the result of careful analysis, testing, and acceptance.

The above scenario may be a simplistic explanation of hypothetical-deductive reasoning. However, it is exactly what scientists do in the process of solving any problems. Adolescent, just like scientists, follow an inquiry process when they are faced with a new problematic situation. That is to say, when they are faced with a problem, they use their hypothetical-deductive reasoning to solve it. This process of hypothetical-deductive reasoning can provide a foundation for a pedagogical approach to education and the design of e-learning environments.

Cognitive Theories as the Basis of Pedagogy

Cognitive and developmental psychologists, Piaget in particular, viewed learning as a dynamic process where learners construct their own knowledge by interacting with the world. The role of teachers, they believe, is not to impose steps, procedures, and rigid structure, but rather to be the architect for learning environments that facilitate a process in which students would be able to construct their own knowledge. This radical approach gave rise to a new group of educators and technologists who became collectively known as constructivists. Piaget's influence upon the constructivist's movement in the U.S. had a great impact on instructional design, teaching models, and educational technology. The main impact of constructivism can be seen mostly in inquiry-training.

Based on Piaget's theory of cognitive development, Suchmann (1962) proposed a constructivist approach for instruction in school which he called an inquiry-training model. The general goal of inquiry-training is to help students develop a sense of the independent inquiry method but in a disciplined way. The process of the inquiry-training model is similar to Flavell's hypothetical-deductive reasoning description that allows the young adult, when faced with a problem, to consider hypotheses, to gather data, and test different hypotheses to come up with a possible solution in dealing with a problem. The inquiry-training model of teaching has the following five phases of instruction:

- Phase One: Puzzlement or intellectual confrontation by presenting students with the problem to create a state of disequilibrium in their mind.
- Phase Two: Students will hypothesize a reason for the puzzlement.
- Phase Three: Students will review and look at models for the new information in regard to the hypothesis and the original problem. Then they isolate relevant information, eliminate irrelevant information, and organize the information.
- Phase Four: Students explore approaches then test their hypothesis to postulate a possible answer to the original puzzlement.
- Phase Five: Students are evaluated to ensure their understanding of the concept(s) in the intellectual puzzlement.

Research conducted by Voss (1982) concluded that the inquiry-training strategy is effective both for elementary and secondary students. The inquiry-training results in increased understanding of science, productivity in creative thinking, and skills for obtaining and analyzing information.

Inquiry-Training and E-learning

During the 1980's and 1990's, influential educational technology theorists such as Papert (1980) became interested in constructivism and inquiry-training models. This new breed of instructional designer believed that construction of knowledge through inquiry, rather than direct instruction, should be the focal issue of teaching and learning. They viewed learning as a process in which children interact with the world to construct, test, and refine their own cognitive representation of the world. Technology is viewed as a tool that allows the development of environments or educational programs in which children through interacting with its elements construct their own knowledge.

With the explosion of the Web as a medium of delivery for instruction, the popularity of the constructivism movement and the inquiry-training models of teaching also took a rise in popularity. Proponents of the inquiry-training model often expressed their dislike for the traditional computer-based approach of tutorial and practice and drill. With the rise of the Web and hypermedia, the philosophy of inquiry-training was applied to technology under a variety of different terms such as project-based training, guided inquiry, inquiry-based, problem-based learning, and resource-based education.

All of these different approaches to the inquiry-training process share attributes that were first proposed by Suchmann (1962). The vast majority of these methods emphasize the same attributes that can be summarized into 1) presenting a problem that represents an academic concept such as mathematics, 2) reviewing prior knowledge about the concept, 3) modeling real life situation as they relate to the academic concept, 4) exploring the academic concept, 5) practicing to demonstrate clear understanding of the concept, and 6) evaluating. Discussion plays an essential role at every stage of inquiry-training which leads the students to find a possible answer to the original problem.

The author of this paper has developed several successful and effective e-learning sites using the inquiry-training model. One such program is Math, Science, and Technology for students in grades 5-8 where they are confronted with an intellectual problem and try to solve the problem based on the inquiry-training model. This site was developed under the direction of the author of this paper and his graduate students in the Educational Technology program at the California State University, East Bay. The Math, Science, and Technology site uses online multimedia activities and off-line inquiry explorations to engage students in guided inquiry aligned with the inquiry-training model. As seen in Figure 1, the first tab "Problem" presents the problem students need to solve. The second tab "Review" presents background information that students need to understand the new concept. The third tab "Model" presents situations in real life that relate to the mathematical concept to be learned. The fourth tab "Explore" presents the mathematical concept to be learned. The fifth tab "Practice" is where students are assessed about the content. Finally, the sixth tab "Discuss" is where students need to go to discuss their findings and their problems with the teacher and other students.

As one of the requirements for the course, each graduate student was responsible to develop an inquiry-training model Web site to teach mathematics aligned with the California Mathematics framework. The result is a collection of simple, uniform, and effective math sites for elementary and middle school students. All sites share the same navigational menu as it was originally developed by the author of this paper.

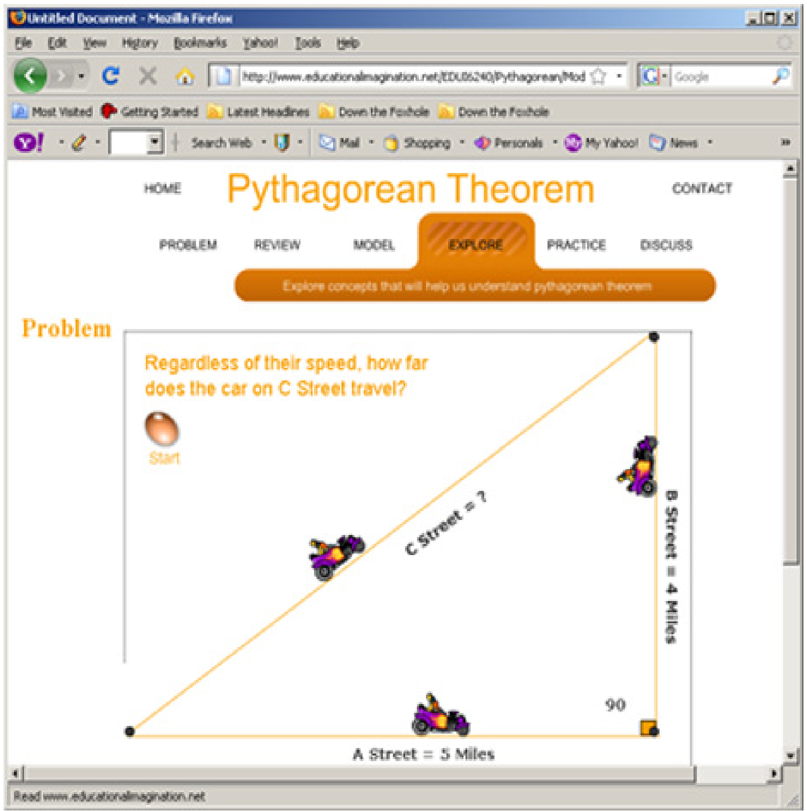


Figure 1. Math, Science, and Technology for the Pythagorean site
http://www.educationalimagination.net/EDUI6240/home.html

In all the Web sites in Math, Science, and Technology, the audiences (students in grades 5-8) are first presented with a problem or the intellectual confrontation in the form of a realistic life situation that has a mathematical solution. The problems are aligned with the California Mathematical Framework. Students hypothesize about the aspects of a solution to the problem and discuss solutions in the chat area included in the site with the teacher as the moderator. The navigational menu reflects the inquiry-teaching process to better understand how they can provide the answer to the problem. As new members of the Math, Science, and Technology group, the students get more information through the navigational menu that will help them to review the mathematical concepts that relate to the original problem.

The next navigational button presents modeling from real life that relates to the mathematical concept under investigation. For example, if the mathematical concept is Pythagorean Theorem, then video and animation is provided that explains the diamond of a baseball field and asks how far it is from first base to third base. Or a video can show a building with a specific height and ask what size ladder is needed to climb to the top of the building if the ladder is placed four feet from the base of the building. These types of videos or animations will help students create a conceptual map in their brain about the Pythagorean Theorem.

Next, Students conduct this research by engaging in multimedia training modules that allow them to explore different aspects of the original problem. By focusing on interactive animation about the mathematical concepts, students begin to understand and internalize the mathematical concept and connect that to their prior knowledge. This process helps them to connect their new knowledge to their existing schema and, therefore, restructure their schema (Accommodation). From these observations, students are encouraged to discuss their findings in the private chat room that is provide on the web site and to draw conclusions and find a solution to the original problem.

Once students have generalized needed conditions of "what" we need to solve the problem, they conduct further research in off-line classroom activities that also follow the inquiry-training model and help students to understand "why" we need these mathematical concepts to solve the problem. These off-line activities engage students in explorations that guide them in discovery learning of concepts. For example, after gaining an understanding of the Pythagorean formula ($a^2 + b^2 = c^2$), students relate the formula to the original problem and the models. Then they can realize whether their original hypothesis about the problem was correct or not. From this inquiry-training process the students "discover" and conclude that the Pythagorean formula has application in real life. This type of learning through discovering on their own research and exploration will stay with the students for the rest of their lives.

The inquiry-training model, based on Piaget's concept of learning, allows students to simulate the methods scientists might use to collect data on various scientific explorations. The model that has been presented here is not restricted to mathematics. It can be applied to any academic discipline.

The Math, Science, and Technology Web site is not restricted to the Pythagorean formula, which was originally designed and developed by the author of this paper. There are more than twenty-five other sites included in the main site. These sites were designed by the graduate students. There are a variety of mathematics topics that are aligned with the California Mathematics Framework. The most significant aspect of all these sites is that the Web is used as an appropriate instructional delivery medium to apply Piaget's cognitive theory to create e-learning environments. The result is a collection of simple, uniform, and effective inquiry-training mathematical web sites for the elementary and middle school students.

Conclusion

In this paper, I have presented a different approach to the design of e-learning environments. While traditional instructional design promotes a structured approach to the development of educational technology programs, the cognitive approach supports a guided learning that allows the learner to construct knowledge while in the process of learning. Just like any other theoretical foundation for instructional development, there are those who support a cognitive approach to technology (Jonassen, 1991; Papert, 1980), and there are also those who claim that the cognitive approach of unstructured learning is not the best use of technology (Laurillard, 1993).

The cognitive approach that impacted the development of constructivist e-learning has a stronger basis in learning how to learn than the traditional structured approach. It also provides a new approach to the new attributes, such as hypertext and hypermedia that are found in modern technology. Many of the concepts that I presented in this chapter such as the inquiry-training model and the discovery-learning approach have influenced the development of successful and effective e-learning environments. In general cognitive approach is more difficult and more expensive to be used to design and develop e-learning environments. However, high cost and difficulties in design should not be the basis of what kind of effective e-learning site one should develop. If your research shows that a cognitive approach is the best suited for your project, then it must be implemented.

References

Anderson, R. A., & Pearson, P. D. (1984). A schema-theoretic view of basis processes in reading comprehension. In P. D. Pearson (Ed.), *Handbook of reading research* (pp. 255-292). New York: Longmans.

Flavell, J. H. (1985). *Cognitive development* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Laurillard, D. (1993). *Rethinking university teaching: A framework for effective use of educational technology.* Routledge.

Jonassen, D. (1991). Evaluating constructive learning. *Educational Technology, 32*, 28-33.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas.* New York: Basic Books.

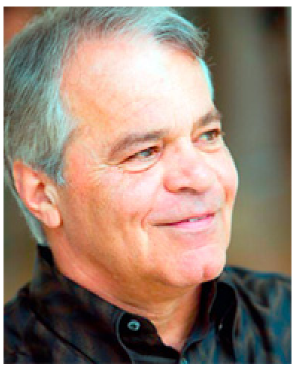
Piaget, J. (1952). *The origin of intelligence in children.* New York: International Universities Press.

Piaget, J. (1964). Development and learning. In R. E. Ripple & V. N. Rockcastle (Eds.), *Piaget rediscovered: A report of the conference on cognitive skills and curriculum development*. Ithaca, NY: Cornell University, School of Education.

Suchmann, J. R. (1962). *The elementary school training program in scientific inquiry.* Report to the U.S. Office of Education, Project Title VII. Urbana, IL: University of Illinois.

Voss, B. A. (1982). *Summary of research in science education.* Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

Biography



Bijan Gillani received his doctorate from the University of Southern California in Curriculum and Technology. Currently he is a professor of Educational Technology in the California State University, East Bay. His pioneering work in using the application of learning theories and the design of e-learning environments has earned professor Gillani the prestigious George and Miriam Phillips Award as the 'Outstanding Professor' at California State University, East Bay for 2008-2009. Professor Gillani is the Coordinator of the Graduate Program in Educational Technology Leadership and teaches courses in “Learning Theories and the Design of E-learning Environments”, “Web-based Instruction”, “Instructional Content Development”, Educational Interface Design”, and “ColdFusion for Educators.” He was the key player to establish three graduate programs in Educational Technology Leadership, Multimedia, and Online Teaching and Learning for the California State University, East Bay. He is also the Director of two grants for integration of technology into curriculum. Currently he is the principle investigator for a partnership with Utalii College in Kenya. He has been a keynote speaker and presenter at conferences on the integration of multimedia in education, e-learning, and has consulted for public and private agencies, and educational institutions. He worked very closely with NASA Ames to design and develop an educational Web site (e.g. Astro-Venture). Most recently, he was the keynote speaker at the “Information Literacy” Conference, presented at the “IBM Interface Design” Conference at the IBM Research Center in New York and San Jose (1999-2003), Keynote speaker in ITiRA Conference at Central Queensland University, Australia (1999-2003), California Science Teacher Association (2006), The Corporation for Education Network Initiatives in California Conference (2004-2005), University of Johannesburg (2007), and others. He is scheduled to present at the University Cassino in Italia in June 2010. He is a prolific author in the field of learning sciences and technology. He has over thirty five chapters in different books and journals. His last book is:
Gillani, Bijan B. (2003). Learning Theories and the Design of E-Learning Environments. Lanham, Maryland. University Press of America.