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Developing Scientific Thought in a Logo-Based Environment

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1. Abstract

For the past several years I have been working to create an intellectual laboratory in which elementary school students learn the scientific method while developing mathematical thinking and problem-solving skills. My goal is for students to approach the acquisition of new scientific knowledge in an environment that inspires the type of intense passion, interest, and purposeful exploration one would observe while watching a student "play" with their chemistry set at home. How unfortunate it is that much of the tinkering, fun, and sense of discovery present in the pursuit of scientific knowledge has been replaced by the artificial, fact-based and passive text-book centered science curriculum present in many schools.

Three Logo-based environments; LogoWriter™, LEGO® TC logo, and the Phantom Fishtank™ create a dynamic environment for learning critical scientific concepts and experiencing the process of science. Science is something you **do** as well as study. When used together, these three software environments extend the types of experiences possible with the best simulation software by providing the student scientist with an opportunity to test and observe scientific phenomena in a universe they control. Problem solving is natural in the context of the student confronting real problems while in the pursuit of knowledge. Rarely does the student confront a question the teacher or textbook doesn't have an answer for, and they almost never have a question the world doesn't have an answer for. This paper will attempt to share ideas for activities in which this "real" scientific inquiry may occur.

2. Introduction

Can anybody remember elementary school science? Most educators would agree that one of the greatest areas of deficiency in our schools is science education. While the symptoms of mediocrity may be present at the secondary school level, the prognosis for elementary school science education is presently terminal.

Most elementary school science education (like other curriculum areas) is textbook based. Students are expected to memorize a set of facts about plants, animals, and rocks and abstract formulas which have very little to do with their everyday experiences, or in fact, real science. While this collection of facts may be important to a child's development, school children rarely get the chance to experience what it is to **be** a scientist and the "magic of science" - to learn the powerful ideas that emerge from the ability to draw upon one's curiosity and experiences to create an experiment, test and refine a hypothesis, and draw conclusions. Elementary school students are hard-pressed to comprehend how the seemingly random facts and formulas being imposed on them may be useful in their lives.

These problems do not end at the elementary school. Despite the fact that secondary and college teachers are normally trained and knowledgeable in their subject matter, students are more often than not deprived of the experience of exploring new scientific ideas and making the knowledge their own.

High school and college students are still required to memorize formulas which they don't understand so that they can regurgitate them on an exam. The underlying concepts are often abandoned in a quest for the right answer.

"In the current era of emphasis on science education, it has become a cliche to call scientific research a great adventure. Well it may be, but the student approaching his first hard science course with this maxim in his mind is in for a rude shock. Rarely does much of the sense of adventure manage to come through the hard work, for the subject matter often seems both difficult and dull. The student headed for a scientific career is usually told that he must face diligent drill before he can understand anything really profound." (March, 1980)

Education, especially science education, need not be a passive experience. Students should be actively engaged in constructing their own knowledge. This paper will address these issues by focusing on three computer environments, LogoWriter™, LEGO TC logo, and the Phantom Fish Tank™, which enhance the study of science without abandoning the need for manipulatives and the learning of fundamental concepts. Being Logo-based, they require minimal confusion and offer maximum flexibility. With increased access to such powerful intellectual tools, children have the ability to create their own scientific models and solve problems that are intrinsically interesting to them. They extend the type of experiences possible by even the very best of simulation software and manipulatives because now, budding scientists can test and observe real-world (and non-real) phenomena. The microcomputer is used as a transparent open-ended tool for scientific inquiry - a laboratory for studying the great discoveries of scientists and a telescope into a world of infinite questions.

Although LogoWriter, LEGO TC logo, and the Phantom Fishtank contribute differently to the creation of the scientific culture, there are a number of important educational themes common to all three environments:

1. Out of simple beginnings complex structures may emerge.
2. Each environment is child-centered. Students are motivated to think and solve problems because the problems were generated by themselves in the process of creating a project.
3. Debugging is encouraged and strongly parallels important aspects of the scientific method. Experience in debugging encourages a healthier attitude towards learning and provides students with strategies for approaching any problem.
4. Each computing environment has "no threshold and no ceiling." Students are free to explore, create, and learn at their own level. Students are challenged by their imaginations. They will never reach the limits of the software.
5. The three environments support the philosophy of constructivism, embraced by Piaget and Papert. Students learn new concepts by reflecting on previous experience and constructing their own intellectual models.
6. The materials discourage passivity. Learning becomes an active and exciting life-long process.
7. The three computing environments are Logo-based so that the "young scientist" need only learn one environment, set of syntax, and rules of behavior. Fluency with the materials allow for creativity and intellectual discovery.
8. All three environments encourage cooperative learning and collaborative problem solving. Students help each other explore new intellectual frontiers.

3. Enter Logo

In Dr. Seymour Papert's now classic book, *Mindstorms*, he presents a profound vision of what he calls a "Mathland." Papert is also critical of the way mathematics and science is presented to children as a collection of abstract facts which have very little to do with a child's personal experiences or interests. Papert suggests that this is why so many children suffer from "mathphobia." I would extend this feeling of detachment to explain student's "sciencephobia" and perhaps more importantly teacher's "sciencephobia."

In "Mathland" students would be as fluent and able to converse in a mathematical language as a living language. It is like learning French by going to France and being immersed in a culture that speaks French instead of attempting to learn French in an American classroom. I hope to extend Seymour Papert's powerful ideas by conveying a vision of a "Scienceland" in which students (and teachers) will feel comfortable thinking scientifically.

The line between math and science may seem blurred. This ambiguity is desirable and compatible with the Logo philosophy of conveying to students a sense that knowledge is unified. If a person learns to think scientifically or mathematically, they will be able to solve problems in other domains. If students learn scientific concepts in a meaningful context they no longer learn **about** science - they actually **do** science by becoming part of the problem they are attempting to solve.

Logo, a powerful programming language built on an even more powerful educational philosophy based on the ideas of Piaget, Dewey, and Montessori, provides an environment in which students can say "What If?" and solve problems in almost any curriculum area. In fact, working in Logo often blurs the artificial distinctions between disciplines by providing a medium for expressing yourself. In the process of solving a problem the student is free to explore many routes towards a solution; selecting the route or parts of routes that are compatible with their learning style and experiential background. Students are confronted by unanticipated problems while working in Logo. The ability to creatively solve problems in a natural, meaningful manner empowers the student to be a better learner. In the best Logo cultures, the child is the most important aspect of the curriculum. Learning becomes an active experience and the student is empowered by the realization that they are in control of their own learning.

Logo programming is a scientific activity. The programmer begins with a goal or problem he/she wishes to solve (the problem may change several times), then they test and refine their program until their problem is solved satisfactorily. The goal is not to learn to program in Logo, but rather to use Logo as a transparent tool for solving a variety of problems. In this context, students learn to program because programming is necessary in accomplishing their goals.

One of the most educationally beneficial and engaging aspects of programming is the debugging process. The valuable by-product of learning debugging skills is a new attitude about errors.

"Errors benefit us because they lead us to study what happened, to understand what went wrong, and, through understanding, to fix it. Experience with computer programming (especially in Logo) leads children more effectively than any other activity to 'believe in' debugging." (Papert & Brand, 1987)

In *Mindstorms*, Dr. Papert adds:

"Many children are held back in their learning because they have a model of learning in which you have either 'got it' or 'got it wrong.' But when you program a computer you almost never get it right the first time. Learning to be a master programmer is learning to become highly skilled at isolating and correcting bugs, the parts that keep the program from working. The question to ask about the program is not whether it is right or wrong, but if it is fixable. If this way of looking at intellectual products were generalized to how the larger culture thinks about knowledge and its acquisition, we all might be less intimidated by our fears about 'being wrong.'" (Papert 1980)

The following relevant quote is also attributable to Seymour Papert: "The question the Child Answers, He always answers correctly." It should be obvious how the acquisition of debugging skills and a healthier intellectual attitude towards debugging has a positive effect on the scientific process. Debugging enhances students' ability to understand not only science, but any new piece of knowledge.

Generations of children have spent hours fascinated by their chemistry sets, LEGO, and tinkering with broken radios and mechanisms. My goal is for the Logo-based activities outlined in this paper to inspire the same type of excitement and scientific inquiry in the classroom that the chemistry set provided in the home.

4.1. LogoWriter

LogoWriter combines all of the power of Logo with programmable word processing, four turtles, thirty customizable turtle shapes, and a vastly improved/simplified user-interface. LogoWriter is a tool which can be shaped by a culture of users based on their needs. I have identified three broad categories to describe ways in which LogoWriter can be used by students as a tool for developing scientific reasoning and to solve scientific problems. I will illustrate how LogoWriter can be used to 1) Simulate scientific phenomena; 2) Collect and interpret data; and 3) As a catalyst for powerful thought.

4.2. Simulating Scientific Phenomena

One of the best ways in which microcomputers are being used as a tool for learning/teaching science is in simulating phenomena that would be too dangerous, costly, large, or slow in the real world. Computer simulations often provide the learner or scientist with greater control over experimental conditions than in real life. LogoWriter can be used by students, even elementary school students, to create models of scientific phenomena, alter experimental conditions, make observations, and arrive at conclusions. Advanced scientific practices such as comparing experimental and control data can also be done in LogoWriter.

For purposes of this paper, I would like to illustrate one scientific concept which many students have explored in LogoWriter; the concept of motion. Due to LogoWriter's multiple turtles and customizable shapes, many students enjoy creating their own animations. Animation is something children love and is an outstanding problem solving activity in that it requires many trade-offs between aesthetics and the microcomputer's inability to do more than one thing at a time. Animation causes a conflict between sequential and parallel processes. Children learn elements of physics, geometry, art, time and space, and programming, while designing an animation.

A basic element of animation is motion. Set the shape of the turtle to a car and ask, "How would we make a car drive in LogoWriter?" This question leads to all sorts of implications of vector quantities - the turtle needs to have a direction and a magnitude (velocity). "How would we make the car drive with a constant speed?"

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REPEAT 10 [FD 1]
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What happens if you type:

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REPEAT 100 [FD 1]
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"How would we make the car go faster?"

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REPEAT 100 [FD 2]
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How much faster did the car go? The answer should be twice the speed of the first try because the car went twice the distance in the same amount of time. Try substituting different numbers, then predict and observe the effect.

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REPEAT 100 [FD 5 WAIT 1]
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WAIT causes Logo to pause for a specified number of counts. How did the car behave now? The WAIT 1 can represent a force resisting the forward momentum of the car. The physics term for this phenomena is friction.

Other concepts have been simulated including: velocity, acceleration, life cycles, chemical reactions, plant growth, orbits, constellations, and volcanoes.

4.3. Collecting and Interpreting Data

LogoWriter may be used create charts, graphs, diagrams, and reports to explain observations or data. The ability to communicate scientific knowledge can be enhanced with graphics, sound, and animation. Junior scientists can use LogoWriter's word processing capabilities to painlessly keep track of hypotheses, procedures, and data. One way in which computers are particularly useful is in collecting data from external microcomputer-based laboratory probes.

A group of imaginative ten year-olds was disappointed by the less than dramatic performance of a burglar alarm activity (from Broderbund's Science Toolkit) using an analog light sensor to detect an intruder. The students decided that their burglar alarm should sound an alarm and flash a message on the screen. They were then faced with interpreting the 0-255 range of numbers reported from the probe, the inverse relationship between the probe reading and the amount of light, and calibrating the probe and software. By writing two simple, one line, LogoWriter procedures, they had invented an obnoxious burglar alarm that became the sensation of the school.

4.4. A Catalyst for Scientific Thought

There are many simple LogoWriter activities which encourage students to think scientifically - to make, test, and refine hypotheses, modify the experiment, and possibly draw conclusions. These "experiments" begin with small Logo procedures and can be left for students to explore with for weeks.

4.5. A Microful of Monkeys

One experiment explores word games and probability. This experiment is inspired by Seymour Papert and the idea that if an infinite number of monkeys sitting at an infinite number of typewriters, they would eventually type the entire works of Shakespeare. We will set less lofty goals. Our objective is to explore randomness and linguistics by creating random words in the hopes that the word CAT will appear. Using simple procedures, students can control variables/randomness, collect large quantities of experimental data, and analyze the data by determining the percentage of English words created by the experiment.

This activity is a nice vehicle to combine linguistic issues with combinatorics and probability - an opportunity to reinforce the concept of mathematics being a language of science.

A complete set of activities and Logo procedures based on this theme and others are available from the author.

5. LEGO TC Logo

Jean Piaget tells us that children are wonderful learners and that they rediscover a vast amount of knowledge as they grow. However, he was puzzled that despite children's enormous potential to learn, they are often incapable of learning even the simplest things in schools. Piaget concluded that children learn best when they have materials from their culture to play with. Even school dropouts are often able to make change or read comic books. But when knowledge is not well represented in the culture, or feared by a culture - as in math, science, and grammar - children fail to learn. Papert applies the term constructionism, to the process of being actively involved in constructing one's own knowledge.

There are few materials in a child's culture with which they are more comfortable and passionate about than LEGO construction toys. Building with LEGO is an activity which embodies the philosophy of constructionism and Logo. With LEGO bricks children can build anything their imagination suggests and complex structures can be built out of simple elements - just like programming in Logo. The Logo vision of being an educational environment with "no threshold and no ceiling" is shared by LEGO.

LEGO TC Logo combines the LEGO TC materials - LEGO bricks, motors, gears, pulleys, lights, sensors - with a special version of LogoWriter called LEGO Logo. Students build machines with the LEGO materials and control them by programming in Logo through a simple, yet powerful, microcomputer interface.

With LEGO TC Logo, students learn first-hand, concepts in engineering, mathematics, physics, electronics, robotics, gears, calibration, feedback systems, and computer science. Students wrestle with trade-offs such as power vs. speed. They learn science with unbridled enthusiasm when science is encountered in a meaningful, concrete, and fun manner. With LEGO TC Logo students assume a role they rarely get to play, that of an inventor. They are encouraged by the materials to invent their own knowledge and invent their own machines. With LEGO TC Logo, students can build new and imaginary machines and models of real-world machines.

As "real inventors" and "real scientists" children, students are much closer in contact with the truly important ideas of science. The emphasis shifts from rote learning of facts and techniques to a new way of thinking that requires systematic, critical, and creative thinking. With LEGO TC Logo children truly care about their work. Appropriation is an important aspect of Piagetian learning and constructionism. Children are not inhibited with LEGO TC Logo by the threat of failure or of being wrong. They can pursue all sorts of ideas, even seemingly silly ones. Who knows? Someday we may have wind-powered cars, a computer controlled mousetrap, or a xylophone playing robot.

Important concepts such as friction are no longer understood superficially by rubbing two blocks of sandpaper together, but rather more accurately as an opposing force keeping my car from performing the way I want it to. Friction takes on a vastly different level of importance. A framework has been set for more formal understanding.

"With LEGO TC Logo, students have an environment in which children can readily develop an understanding of the process of science. Children develop theories to describe the behavior of the things they build, then run experiments (designed by them) to test out their theories." (Ocko, Resnick, 1987)

While developing their LEGO TC Logo projects, students use scientific techniques, methods, and terminology based on necessity. Students think analytically and are often overheard to be discussing units of measure - how fast something traveled, how big their invention was, is a gear transmission more efficient than a belt transmission? These too often abstract concepts are now internalized by students.

LEGO TC Logo provides opportunities for academic success for students with strong spatial and mechanical skills who may not perform well in traditional classroom settings which emphasize memorization, verbal skills, and artificial top-down problem solving strategies.

6. The Phantom Fish Tank

The Phantom Fish Tank must be explored to be appreciated. The Fish Tank's author, Brian Silverman, refers to his book and accompanying software as "an ecology of mind" and "mathematical recreation." The Phantom Fish Tank is a laboratory for doing real science in an unreal world. In this world you have complete control over all of the rules, conditions, and variables. Users not only get to make scientific observations, form and test hypotheses, and draw conclusions, but they also experience being the creator of the world they are studying. This experience certainly cannot be replicated in a traditional classroom.

The Fish Tank deals with cellular automata, a branch of mathematics and computer science which strives to create a universal computational object and computers, not based on electricity which can reproduce themselves. Cells are placed on the screen's 40 X 40 matrix and then behave - reproduce, die, move - according to simple rules. Brian Silverman's book with the Phantom Fish Tank provides examples of how cellular automata can be used to explain principles of genetics, electricity, evolution, physics, mathematics, biology, and computer science. The most famous cellular automata "game" was created by John Conway and called "The Game of Life." Where the Phantom Fish Tank differs from other "Life Games" is that it is built on a version of Logo which makes it easy for the "scientist" to control his/her laboratory, collect data, and store new life forms. There is a built in rule editor that allows the student to create his/her own new rules of behavior for the world.

The Phantom Fish Tank appeals to different people on many different levels. Dr. Cynthia Solomon suggests that children learn best with materials that are graphically interesting. The Fish Tank's graphics generate enough interest for years of study. The author compares the software to a microscope and some of the "sample slides" (files) included with the software help illustrate logic gates, diodes, circuitry, inverters, organisms, calculators, and other physical objects in a non-physical environment controlled only by simple rules of how a cell should interact with neighboring cells. He goes on to state that no scientist would want a microscope which can only work with prepared slides. The furtherance of science is dependent on the ability to create your own slides and the Phantom Fish Tank's software provides a flexible laboratory environment for exploring millions of possibilities.

7. Putting it All Together: Logo from Another Planet

One open-ended activity with potential for individual and group discovery is creating new life forms in Logo. A new and exciting multidisciplinary area of scientific research is called, artificial life. Artificial life research combines elements of psychology, physics, artificial intelligence, mathematics, biology, and computer science with important intellectual ideas, including: emergence, bottom-up design, and systems-oriented thinking. The intellectual tools sharpened in this activity have relevance far and beyond the field of artificial life research. If it is in fact important for students to develop problem solving skills, I am hard pressed to think of a more fertile pursuit than creating a new universe and its inhabitants.

"In certain fields, such as high-energy physics and much of current mathematics, it is difficult to make cutting edge ideas accessible and relevant to children. But that is certainly not the case with artificial life. Children all share a strong interest in living things and animal behavior. Moreover, the general approach to artificial life research is one that meshes nicely with children's natural ways of learning. Artificial life researchers often learn by building things. They start with simple, easily understood rules or units, and they study how complexity emerges from interactions among these units." (Resnick, 1987)

The classic Elementary School Science Curriculum's unit on observing mealworm behavior is an excellent introduction to artificial life.

The creatures the students invent can be models of real-life animals or new organisms, never seen before. Issues of locomotion and movement can be modeled in all three Logo environments. Some behaviors and senses can be better simulated in LogoWriter or LEGO TC Logo. For example, the sense of touch can be dealt with by a screen creature in LogoWriter who will bump its way through a screen maze or a LEGO creature programmed to navigate a physical maze. Sight and visual perception may also be modeled in both environments. Smell, hearing, and taste are better simulated in LogoWriter because they are not dependent on the LEGO TC Logo light and touch sensors. Issues of reproduction and colonization may be explored with the Phantom Fishtank.

What happens when we combine several of the mechanical emotions of psychologist Valentino Braitenberg's vehicles? How does a creature with one eye behave differently than a creature with two eyes? What happens if a predator is added to your world? How could you simulate social behaviors?

8. Conclusion

I have attempted to illustrate how students, beginning in the elementary school grades, can construct their own scientific knowledge and, thereby, learn to think scientifically in more meaningful and effective ways than are commonplace today. My tool of choice for stimulating interest and understanding of scientific concepts is the microcomputer. I use the microcomputer in the way Seymour Papert would like to see the computer used; as a transparent tool always available to the student for solving problems that are intrinsically interesting and important.

The three Logo-based environments I have discussed place the child in control of his/her own learning. The curriculum is designed to be child-centered and not only teach a collection of discrete facts, but empower the learner by providing challenging opportunities for fun, self-expression, problem solving, and a love of life-long learning.

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