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Research on Logo: Effects and Efficacy

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First grader Darius never talked aloud, was slow to complete his work, and had been placed in a "socialization group" to "draw him out of his shell." When the computer arrived, Darius spent nearly 90 minutes working with the Logo turtle on his first day. Immediately thereafter, his teacher noticed that he was completing seatwork without prompting. Then he would slide his seat over to the computer and watch others program in Logo. A bit later, he stood beside the computer, talking and making suggestions. When others had difficulties, he was quick to show them the solution. Soon, others started getting help with Logo from him. In brief, Darius moved up to the high reading group, skipping the third preprimer. He began completing twice as much work per day as he had previously. He participated eagerly during class discussions and--as a "crowning achievement"--was given a 10 minute "time out" because he wouldn't stop talking.[1] Are such results merely happy circumstances, or replicable benefits of certain Logo environments? What does the research say?

Logo research has a short but rich and varied history. While there is no one "effect" of Logo, there are many benefits and difficulties that should be researched. Fortunately, there has been enough research done to form a foundation on which we can build. This review will attempt to sample a few key topics within this foundation--mathematics, problem-solving, language and reading, and social/emotional development.

Mathematics

The Logo programming language was first developed to help children learn math.[2, 3] Much of the literature on Logo has presumed that **exposure** to math concepts alone while using Logo increases math achievement. Research on this topic is inconclusive.

Classroom observations have shown that children do use certain math concepts in Logo programming. Children as young as first grade apply such mathematical notions as number, arithmetic, estimation, measure, patterning, proportion, and symmetry to their Logo work.[4] Similar observations of intermediate grade children indicate that Logo may make it possible to explore some math concepts earlier than is currently believed. [5,6] Although traditional obstacles to understanding math concepts do not disappear, we should not underestimate the achievement of the children in Logo environments.[7,8]

So, Logo enhances mathematics achievement. We don't know, however, whether *any* type of exposure leads to increased achievement, as measured by test scores. Some researchers report significant gains[9] and even dramatic learning changes for as many as 10% of students.[10] Others, though, reveal mixed results[11] or no significant differences between Logo and control groups .[12-15] Maybe Logo provides practice only with limited topics. Possibly achievement tests assess only limited areas of mathematical knowledge. Or perhaps the "exposure hypothesis" is not fully adequate, especially given the brief exposure provided by most of these studies.

In contrast, *exposure alone is not what the developers of Logo had in mind.* They intended it to be used as a *conceptual framework* for learning math. As students program in Logo, they explore mathematical relationships. They play with angles, numbers, and variables. They think about their actions. This permits them to build up initial ideas and experiences that serve as a *framework* for learning formal mathematics.

Geometry

Geometry provides an example. Children's initial ideas about shapes and space are based on action.[16] Logo activities designed to help children build on their intuitive ideas about *paths* may help them develop their ideas of two-dimensional shapes. [17, 18] For example, having students visually scan the side of a building or walk a straight path will give students experience with straightness. But students can be made more aware of this idea with path activities in Logo. It is easy to have students use the turtle to discover that a straight path is one that has no turning.

Also, Logo can help children learn *higher levels of geometric thinking.* A husband-and-wife research team, the van Hieles, discovered that students' thinking develops through a series of levels.[19]

Visual level: Students see shapes as "wholes" only.

Descriptive level: Students can describe the properties of shapes (a rectangle has four square corners and opposites sides that are equal and parallel).

Analytical level: Students generalize the logical relations that exist among figures and their parts and reason deductively (all squares are rectangles).

According to the van Hieles, students don't move from one level to the next without instruction that passes through a series of phases. If instead teachers use concepts and language from a higher level, students will merely memorize instead of understanding important relationships.

Using the Logo turtle helps students progress to higher levels of geometric thinking. Students at the *visual level* are able only to identify examples (rectangles "look like doors"). In Logo, however, students can be asked to make a sequence of commands (a procedure) to draw a rectangle. In writing a rectangle procedure, the students must *describe* and *analyze* the rectangle and reflect on how its parts are put together. If the students are asked to write a more general rectangle procedure, they must construct a definition for a rectangle that the computer understands. They then begin to build intuitive knowledge about defining a rectangle. This knowledge can later be formalized into an abstract definition.

A class of first graders was investigating the concept of rectangle. The students had identified rectangles in the classroom and built them out of various materials such as blocks, tape, clay, and geoboards. They then went to the computer lab and were asked to make the turtle draw rectangles.

As the activity proceeded, all children were drawing rectangles in Logo. One of them tried to be different; he attempted to draw a rectangle that was tilted. He instructed the turtle to draw the first side using 5 FORWARDs. He paused for quite some time as he came to the first turn, so the teacher asked him how much he had turned before. He said three RIGHTs and hesitatingly tried three. It worked to his satisfaction and he then drew the second side. He hesitated again, saying out loud, "What turn should I use?" The teacher said, "How many turns have you been using?" He quickly issued three right turns, then hesitated again; "How far?...Oh, it must be the same as its partner!" Effortlessly, he completed his rectangle.

Even though this child had built several rectangles with sides horizontal and vertical, it was not obvious to him that the same commands would work for a tilted rectangle (or indeed that there was such a thing as a tilted rectangle.) He had clearly learned that the opposite sides must be the same length, but he had not figured out the measure of the turns. The Logo environment provided him with the opportunity to analyze and reflect on the properties of a rectangle.

Primary school children, after using Logo, see shapes as *created by actions*.[20-22] When asked to describe geometric shapes, they offer not only more statements overall, but also more statements that explicitly mention properties of shapes, an indication of *descriptive* thinking.[18, 21, 23]

Logo helps students think about angles.[21, 24-27] These benefits, however, might not emerge until they have had *more than a year* of Logo experience.[28] Also, teachers need to help students understand the relationship between "turtle turn" and "angle measure."[20, 26, 29-31]

Students also learn about length measurement. Logo children are more accurate than control children in measurement tasks.[32] They can better estimate longer distances and use different units of measure.

Although promising, not all research has been positive. First, it should be noted that none of the studies have reported students' "mastery" of the concepts investigated. In addition, without guidance, misconceptions can persist. Second, some studies show no significant differences between Logo and control groups.[33] Third, some studies show limited *transfer* to activities outside Logo. For example, students from two ninth grade Logo classes did not differ significantly from control students on subsequent high school geometry grades.[27]

One problem is that students do not always think mathematically, even if the Logo environment invites such thinking. For example, some students rely excessively on visual cues and do not work analytically.[7] The visual approach is not related to students' ability to visualize, but to their use of visual feedback. If students continually rely on their Logo programs "looking about right," they do not progress to higher levels of geometric thought. There may be little reason for students to abandon such visual approaches unless they are presented with tasks whose resolution requires a descriptive, analytical approach.

In summary, studies show that success requires thoughtful sequences of Logo activities and much teacher intervention. That is, Logo's potential to develop geometric ideas will be fulfilled if teachers help shape their students' Logo experiences and help them to think about and make connections between Logo learning and other knowledge the student might have.[21, 23]

Variables and Algebra

Teachers and researchers also suggest that Logo will help students understand variables. Logo enhances the understanding of variables for students from the primary grades to high school.[5, 34, 35] In one study, fourth graders were interviewed before and after using Logo to solve problems involving rectangles, formulas and equations, and number sequences.[36] During the pre-Logo interviews, several students used a correspondence between the letters of the alphabet and the positive integers to assign values to variables in equations (i.e., A =1, B = 2, etc.) After using Logo, they determined each variable's value correctly. All the students could use variables in formulas after using Logo, whereas none could before.

However, there are sometimes limitations to such learning. For example, students may not fully generalize the variable idea as used in Logo to other situations.[37] Similarly, after a year of programming experience, high school students had only rudimentary understanding of variables.[38] We may be considering the link between algebra and programming too literally.[39] Most students probably create a new idea of variable in the context of programming. On an algebra test, they use the idea that they learned in math class.

In addition, students often have difficulties with the variable concept within Logo. First, the use of variables does not happen spontaneously, and children resist their use even when suggested.[40,41] Also, students sometimes declare a variable in a procedure, but then do not use it within the body of the procedure; they believe that a variable might have different values within a procedure; and confuse what the variable stands for.[40]

Again, there is evidence that mere "exposure" is insufficient. Logo can benefit intermediate grade students in learning about variables.[42] But they have not necessarily gained specific information about variables or algebra. They may have gained a *conceptual framework*--based on intuitions from Logo experiences--upon which later algebraic learning can be built.

Such construction requires thoughtfully structured tasks. Instruction that emphasizes links between Logo and algebra leads to a more formal and general idea of variable.[35,40,41]

In summary, there is some evidence that Logo provides an "entry" to the use of the powerful tool of algebra. Again, however, we find that students' ability to generalize their Logo-based idea of variable may depend to a great degree on the depth of their Logo experience and the instructional support given them.

Implications

This research has two implications for instruction. First, exposure alone is not completely adequate. A more satisfactory approach features *teacher mediation* and a sound theoretical foundation (e.g., for geometry: Piaget and van Hiele). Mediation implies clarification of the mathematics in Logo work and the extension of the ideas encountered; construction of links between Logo and non-Logo work; and provision of some structure for Logo tasks and explorations. Structure does not imply authoritarianism. For example, it is often useful to allow hesitant students to accept or reject suggestions until they build confidence.

Construction of links between Logo and other mathematics activities might be approached in different ways. One would be to use Logo as a medium to deliver the traditional mathematics curriculum. Another would be to revise and expand traditional activities so that children use higher-level thinking processes in their mathematics classes. The latter more closely aligns with the recommendations of the National Council of Teachers of Mathematics.[43] But it is also challenging--research shows that teachers find it extremely difficult to create a learning environment that fosters creativity within existing school and curricular structures. Those who were able to change their classrooms into an environment that encouraged creative mathematics had to examine fundamental assumptions about teaching, learning, and their professional role as teachers.[5] It may be that Logo should be used in preservice mathematics courses, where it can lead to better achievement and attitudes.[44]

A second implication is tentative, but potentially important. Logo may be a particularly fruitful approach for populations at-risk for poor performance in mathematics, such as girls and minorities. For example, in one study the gap between a 12-13 year-old Logo female group and a control female group widened appreciably during the year. Indeed, the Logo female group overtook the control male group which started the year ahead of all the other groups.[45] In another, using Logo resulted in an increase in internal feelings of personal responsibility and feelings of success for females only.[46] Finally, in a third study, Logo minority students outscored Logo majority students on a standardized test of mathematics achievement.[47] Logo may be beneficial to minority children because it provides them with a sense of mastery over their environment. It builds upon the learning strengths of black students, such as high responsiveness to visual and auditory stimuli and desire to collaborate with and pass on information to peers. This requires a mediated teaching approach.

Problem-Solving

Gina: What do we tell the turtle to make here?

Robbie: That's where the sun is gonna go. We gotta go over here and do a circle with curvy lines around it like our drawing.

Gina: So making curvy lines will be the hard part to figure out....

These students are determining just what the problem is all about and what will be required to solve it. We know that getting students to understand what is being asked of them is often half the battle. Here's the other half...

Gina: We got it!

Robbie: Well, let's think and make sure.

Gina: Put 70.

Robbie: 70? We already did 50. Type FORWARD 20."

Gina: Let's make a list of everything we tried and see which ones [inputs] are best.

The partners are *thinking about their thinking*... checking their work... reflecting. Logo was not only developed to serve as a mathematical tool, but also as a tool for thinking. As with math learning, different approaches to using Logo to develop problem-solving abilities yield different results.

"Exposure" studies are similarly inconclusive. These studies assume that programming and problem-solving use equivalent thinking processes, and exposure to the former would develop the latter. Results are mixed, with Logo programming increasing performance on some tasks but not on others.[48] Other studies are more discouraging--for example, finding no effect of Logo work on students' ability to solve nonroutine, mathematical word problems,[49-51] or reporting that direct training on problem-solving strategies without computers resulted in higher performance than unguided Logo experience.[52]

Another such hypothesis was that programming involved extensive planning; however, middle and high school students exposed to Logo did not display greater planning skills on a non computer task than those in a matched group.[38,53]

Under certain conditions, however, Logo may increase problem-solving ability. For example, Logo can serve as a vehicle for helping fifth and sixth grade students develop mathematical problem-solving abilities.[54] The most positive results occur when teachers mediate their students' learning of problem solving.[55-57]

Why is such mediation important? Some studies show no effect on planning. But observations of students working on Logo tasks show considerable growth in planning.[4,58,59] This growth is slow, however, and without teacher mediation to highlight planning processes, transfer to non computer tasks is unlikely. Students must become *aware* of their planning skills and how they can be used in other situations. In one study, teachers stressed the need to plan a procedure before beginning it and to use strategies such as breaking a large idea into more manageable parts. Their students used strategies of planning and drawing more frequently to solve non-Logo mathematical problems.[60]

Effects on processes other than planning may be more profound. Indeed, regular classroom tasks and tests may already provide substantial experience with planning. On the other hand, such problem-solving processes as deciding on the nature of the problem, selecting a representation for solving the problem, and monitoring thinking are not emphasized. But Logo programming can engage children in all aspects of problem solving. Research supports this notion. For example, students within a Logo environment displayed those problem-solving processes to a greater degree than those in other computer environments, such as computer drill.[61] In addition, they outperformed both this computer group and a non-computer control group on tasks designed to assess these processes.[62,63]

Such findings have important educational implications. Research shows that most students do not monitor their own problem solving, from early childhood to the college level.[64] After they begin working on a problem, they rarely pause to see if the procedures they are using will actually help them solve it. They do not check their work for mistakes and they believe little can be learned from such errors. Why does Logo help? In computer programming, errors are unavoidable. Ideally, "experience with computer programming leads children more effectively than any other activity to `believe in' debugging . . . children learn that the teacher too is a learner, and that everyone learns from mistakes."[3] Thus, the act of debugging Logo programs that do not quite do what was intended provides students with valuable experience in using their monitoring skills.

In appropriate Logo environments, students learn to use monitoring in and out of Logo. In one study, students were given problems that purposely misled via extra or irrelevant information. For example, "When Albert was 6 years old, his sister was 3 times as old as he. Now he is 10 years old and he figures that his sister is 30 years old. How old do you think his sister will be when Albert is 12 years old"? Logo students were more likely to find and fix the error in the problem.[63] Overall, one of the more consistent research findings is an increase in monitoring following Logo experience.[65-67] It is important to repeat that *each* of these studies employed mediation; furthermore, this mediation was based on a theory of human problem solving. In addition, *assessment* was based on processes hypothesized to be affected by the Logo experience, rather than, for example, routine textbook problems.

In sum, there is reason to be guardedly optimistic about the use of Logo to develop problem-solving abilities. A recent study showed that students who had computer programming experience scored about 16 percentile points higher on various problem-solving tests than students without these experiences. Logo programming produced higher scores than computer programming in other languages. To mediate this learning, successful teachers[55,68]

- ask higher-order questions.
- make sure that students are explicitly aware of the strategies and processes that they are to learn.
- discuss and provide examples of how the skills used in Logo could be applied in other contexts.
- provide individualized feedback regarding students' problem-solving efforts.
- ensure that a sufficient proportion of instruction occurs in small groups or in one-to-one situations.
- promote both child-teacher and child-child interaction.
- discuss errors and common misunderstandings.

Language and Reading

There has not been as much research in academic areas other than mathematics and problem solving. Perhaps this is because Logo's originators conceived of it in this way. Perhaps researchers are less aware of the rich potential of Logo in other subject areas. What research has been conducted, however, tends to be positive. Research with young children indicates that Logo engenders language rich with emotion, humor, and imagination.[69] Similarly, 8- to 11-year-olds talked to each other more about their work when they were doing programming tasks than when they were doing noncomputer tasks.[70]

Effects on reading skills are more uncertain. When fifth graders were removed from the classroom for Logo programming lessons, their reading scores declined.[14] Other studies, however, have shown that immersion in Logo can lead to increases in language mechanics and reading comprehension, even without direct instruction in that ability.[15,20] Research is needed to explain these findings.

Social and Emotional Development

Findings of increased language use suggest effects on the classroom's social climate--remember first grader Darius. This may be a surprisingly important benefit of the use of Logo.

Social Initiation and Participation

Teachers report that students exposed to Logo programming are more likely to interact with peers. They engage in group problem solving and sharing; there is more social acclaim by peers, and social acknowledgment of expertise or ingenuity. These benefits are especially pronounced for social isolates.[1,5,10]

Students working in Logo also talk more about learning than those in non-Logo classrooms.[70,71] In sum, Logo environments appear to have the potential to facilitate social interaction, as well as to focus that interaction on learning.

Social Problem Solving

Students engage in more collaborative activity during Logo than noncomputer tasks.[70] They also learn to solve social problems cooperatively and flexibly in that context .[5,72]

One study indicated that children work cooperatively more often on computers than off.[73] Interestingly, they also got into more conflicts (possibly because they interacted more). However, children working with Logo, compared to children working on other computer activities, were more likely to **resolve** these conflicts.[73] In a similar vein, students working together on Logo tasks spent much time resolving conflicts.[23] Finally, research indicates that the *type* of conflict--social or cognitive--is critical.[58] Children working in Logo demonstrated more conflict about *ideas*, and more attempts and successes at resolving these conflicts. Differences were not evident for *social conflict*. So, the effects of Logo seemed to be specific to disagreements about ideas. Opportunities to experience and resolve conflicts are necessary for the development of problem-solving competencies. Therefore, Logo contexts may enhance the development of specific social and cognitive problem-solving skills.

Students working with Logo are particularly prone to helping and teaching each other.[10,70,73] Elementary students working with Logo learn to listen, be critical in a constructive fashion, and appreciate the work of others.[5]

In summary, Logo has the potential to serve as a tool in encouraging prosocial interaction, social problem solving, and social sensitivity.

Emotional Development

What of students' emotional side? Can Logo increase their self-esteem? Their motivation to learn? According to their teachers, students working with Logo experience an increase in self-esteem and confidence, *if* their teacher gives them greater autonomy over their learning and fosters social interaction.[4,5,10] Logo particularly provides special needs children with prestige and respect from their peers, enhancing their self concepts.[74]

Logo work can improve attitudes toward learning and academic subject matter,[5,13,75] although such results are not consistent.[51,76] Children in Logo environments are more likely to engage in self-directed explorations and to show pleasure at discovery.[61,73] Students experiencing Logo appear to judge situations for themselves and accept responsibility for their actions.[13,76,77] These findings provide some evidence of Logo's power for enhancing students' self-esteem and attitudes toward school.

Social Issues: Conclusions

It is important to reiterate that Logo, as conceived by Papert,[3] is more than a programming language: It is a catalyst for the generation of a learning and teaching *culture*. This culture includes children's interaction with others. Furthermore, one of Papert's principles of Logo learning is "cultural resonance": The ideas learned within Logo should make sense in the larger social context. One implication is that future research on Logo should consider the social context in which the teaching and learning are embedded. It is thus not surprising that research results, especially concerning cognitive benefits, have been inconsistent. Several evaluation efforts have disconnected the Logo language from its social and cultural roots, placing it within the traditional classroom context. Their findings are frequently "no significant differences."

The social interactions that occur in Logo environments may be qualitatively different from those in other environments. Child-child and child-teacher interactions during Logo programming may be as significant for social, emotional, and cognitive development as are the child-computer interactions.

Final Words

In conclusion, it appears that while there are certainly no "guaranteed results," Logo has the potential to improve students' educational experiences. A critic might protest that the measure of these benefits is too slight. Criticisms of claims about Logo's benefits ignore four important issues.

First, we must remember that researchers do not know how to measure all that is educationally valuable. Many of the traditional experimental studies of Logo have used traditional measures that would not reveal effects of meaningful educational reform. They use traditional designs that demand that only one "variable" be manipulated. But Logo is an open-ended tool. Teachers and researchers must decide what to do with it: how to present it to students, what tasks to pose, and what classroom interaction to promote. Teachers should then be aware that there is never only one variable. There is no single "Logo effect."

Second, Logo possesses the power to significantly enhance students' educational experience. These benefits are maximized when

- Logo experiences go beyond mere exposure.
- teachers mediate Logo experience.
- the classroom culture--the way teachers and students view learning and each other--is simultaneously changed.
- an active, constructivist approach is taken to the teaching/learning process. This is critical. All recent calls for reform support this approach. Logo is designed to support this approach.

Third, while educational researchers debate the efficacy of various research methods, we conclude that there *is no single best method* for assessing the effects of Logo. Each has advantages--a certain lens that allows us to view people as they use Logo. Each has blind spots.

Experimental studies often overlook the deep meanings people give to their Logo work. These studies usually can't see what the researchers didn't think of looking for. They can uncover small, subtle effects that emerge only as patterns over large numbers of people. And so it goes. Action research empowers teachers. Research in the literary or dramatic tradition provides an aesthetic view.[78] Without this variety, our vision of the effects and efficacy of Logo would be dim indeed.

Fourth, mediated Logo environments are interesting in that they seem to enrich so many different aspects of students' lives. An alternate, narrow approach might yield similar gains on a single test, but few educational environments have shown consistent benefits of such a wide scope, from the mathematical and cognitive to the social and emotional. Like "Stone Soup," the main nourishment of a Logo environment may emerge from many small, interacting contributions. But the local culture has to change to allow the contributions to occur.

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