New Paradigms in Classroom Research on Logo Learning

Edited by Daniel Lynn Watt and Molly Lynn Watt

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About NECC Research Workshops and Monographs

Through the efforts of the NECC '90 Conference Chair, Dr. John McGregor, and with financial support provided by IBM and the ACM Precollege Education Subcommittee, two research workshops were added to the NECC '90 agenda. Research workshops provide a unique forum for researchers to share ideas in special areas of educational computing.

These first two workshops resulted in two monographs. *Problem Solving and Critical Thinking for Computer Science Educators* provides an overview of problem solving and critical thinking and its relationship to computing and education. *In Search of Gender Free Paradigms* by researchers in gender issues in computer science provides recommendations to solve the problem of the declining number of young women selecting computer science majors.

The NECC '91 research workshop focused on Logo research and resulted in this monograph, *New Paradigms in Classroom Research on Logo Learning.*

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D.L.W. and M.L.W.

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Preface: New Paradigms in Classroom Research on Computer-Based Learning and Teaching

Andrew R. Molnar
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Introduction

In general, education can be thought of as serving two functions in our society. First, education transmits the accumulated knowledge and values of the past to the new generations of students. Second, it prepares our children for the world in which they will live.

How well have we done in transmitting past knowledge? On the basis of national and international studies of student achievement in mathematics and science, researchers find that while many schools do a good job and while many of our students are outstanding, collectively as a nation our student achievement levels rank near the bottom of those of industrialized countries. These findings have stimulated recommendations for reforming and restructuring our educational system.

How well do we prepare our children for the world in which they will live? This is a much more difficult question to answer, and possibly a far more important one. While we cannot know the final answer for some time, we may be able to see if we are keeping up with current changes. Numerous studies have shown that we are moving from being primarily an industrial society to being a science-based, information society. That is, high-tech industries built on the application of scientific knowledge have emerged in such fields as biotechnology, energy, computers, and telecommunications.

While these developments have improved our national well-being and international competitiveness, they have also created new stresses on our educational system. Workers in these industries require a new and different type of training. They must, at some level, be capable of understanding science and be able to use higher-order thinking and problem-solving skills.

In addition, the fields of science and mathematics are changing. Powerful new computer and telecommunication systems have greatly expanded our capacity to solve problems and increased our access to up-to-date scientific information. Today, we find that the body of scientific information is large and increasingly more complex. In addition, the growth rate of scientific knowledge is increasing exponentially.

Therefore, unlike previous reform periods, our society is in rapid transition while reform is taking place. What our students need to prepare them for the world of work and the world of science is not as clear as it once seemed. Many past lessons seem obsolete or less important, and many future needs seem missing from the curriculum. In the past, a formal education prepared one for a lifetime of work. Today, education is continually challenged to move from the static world of the past into a more complex, dynamic world that requires educators constantly to change content, pedagogies, and standards.

The advent of new computation and information sciences has empowered scientists and even average citizens to acquire powerful new skills to identify and solve complex problems thought to be unimaginable or unsolvable only a few decades ago. In short, many people have concluded that we are not making the changes necessary to prepare our children. Schools are changing, but their changes are insufficient.

The Teacher as a Researcher

Even with all this uncertainty, the success of our educational system rests on the performance of teachers, no matter what local or national reforms are proposed or implemented. Teachers by necessity are central to any reform and will be instrumental in its success. However, if teachers are to be the catalytic agent for change during this transition, they must seek and experiment with new ways of responding to new and ever-changing demands.

How can teachers help meet these demanding new challenges? Clearly, teachers must learn to use the new intellectual tools that are an integral part of the scientific and technological revolution. In order for students to benefit, teachers must develop new ways to incorporate these tools into the classroom.

Teachers can use research in three ways to improve teaching and learning. First, they can study how to apply to their own teaching new cognitive research on student learning of modern science and mathematics. Second, they can improve their professional judgment by studying those practices. Third, they can share their collaborative efforts and classroom research findings by using telecommunication and information technologies.

As a result of the changing nature of science and technology, a paradigm shift has occurred in recent years in science and mathematics education. Studies of various disciplines have found that the distinction between experts and novices is not necessarily in the factual information held by the expert, but in the way the expert thought about problems. While textbooks tend to focus on the formal structure of a discipline and the factual information within it, they do not usually discuss the problem-solving and cognitive skills necessary to become an expert. Therefore, emphasis has changed from "learning" to "cognition." Many people now feel that it is no longer sufficient to lecture students about factual and declarative information and have them repeat it on tests. Instead, the emphasis now is on teaching the cognitive and thinking skills necessary for problem-solving. Students must gain a deeper understanding of the processes involved in doing science and in using higher-order skills as experts would in solving problems.

However useful these insights may be, however, they are not sufficient. Large-scale research findings can only supplement actual classroom practice. More times than not, research identifies important problems but does not provide specific guidance on how to solve them. Such research is usually based on normative studies of large samples of students and teachers, covering numerous variables with the aim of achieving broad generalizability; teaching, for the most part, is a clinical activity.

Teachers can benefit by using research methodologies to apply research findings in their classrooms. The teacher can use the systematic techniques of the researcher in the classroom to adapt generalized research findings to a particular educational setting and thereby generate new clinical information that can in turn be reapplied. The collection and sharing of classroom experiences can create a new body of applied clinical knowledge that can strengthen the profession.

In summary, the teacher-as-researcher can use results from well-controlled, normative research for teaching new concepts and using new methods in the classroom. However, actual teaching performances will not improve unless teachers conduct their own tests to evaluate those findings as they apply to their own classrooms. Teachers can assess the outcome and modify their teaching accordingly. Sharing that clinical knowledge with other teachers is equally important. This information-sharing can create a critical mass of teachers with both theoretical and applied knowledge who can have a significant impact on the quality of science and mathematics education.

Cognition, Problem-Solving, and Technology

Many educators have adopted a "constructivist" paradigm to learning. That is, students can be given information, but they must construct information for themselves if they are to understand it and apply it. However, Dr. Seymour Papert, one of the co-inventors of Logo, has extended this approach to include the use of technology. In the constructivist theories of psychology, he says, learning is viewed as a reconstruction rather than as a transmission of knowledge. Papert has extended this approach to a theory he calls "constructionism." He asserts that the idea of manipulative materials is extended to include the idea that learning is more effective when the learner constructs a meaningful product as part of an activity. The student is encouraged to define a problem, write a solution to the problem, debug it, and finally make it do something that will solve the problem. In this way the student learns and develops the necessary skills for defining the problem and the tactical, practical problem-solving skills necessary to solve it.

The constructionism approach changes the purpose of introducing computers into the curriculum, from "computer literacy" to "computer fluency." At a very early age, students experience computers as important tools for solving real problems. The computer provides a new basic skill for the student who will be the knowledge worker of the 21st century.

We live in uncertain and changing times, and the demands placed on education are increasingly difficult to meet. To paraphrase Albert Einstein, everything has changed but our thinking. As teachers we must now view the world as it is and will be, not only as it has been. Science has given us new knowledge and powerful intellectual tools and technologies. We must build upon these resources by finding new ways to incorporate them into the classroom if we are to effectively prepare our children for the world in which they will live. The research efforts described in this volume are important steps in the national effort to improve the quality of education.

Introduction: New Paradigms in Classroom Research on Logo Learning

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Why do educators conduct classroom research on Logo learning? How might such investigations be conducted to benefit the practitioner? What collaborations support such research? What is learned from small context-dependent research focused on individual classrooms? What is its value to individual teachers and others?

In this introduction we address these questions and summarize nine classroom research studies. The research reported on in this monograph was conducted by university researchers and classroom teachers who investigated real teaching issues. Each study is a low-budget or no-budget collaborative research project that focuses on effective teaching and on learning and assessment of Logo in classrooms. The research was undertaken by a need to know rather than by a funded professional obligation. These studies are concerned with small numbers of students in specific learning environments. The purpose is to understand, interpret, and improve that learning. The knowledge gathered is usually utilized immediately to the benefit of the cooperating or co-researching students. The educators conducting the research have reported that the process, which is almost always undertaken on top of already over-busy professional lives, is a source of professional renewal rather than burnout.

The research may focus on the need to assess Logo learning in a particular setting in order to justify the time spent on Logo. It may focus on issues of general concern, such as gender-related differences in science and math achievement or on how children use problem-solving strategies. Other studies may address the development of a new curriculum, or they may have resulted from the desire of an individual teacher to teach Logo more effectively by understanding more about what students are learning.

These were among the starting points for a group of educator-researchers who came together in a one-day miniconference on Logo Classroom Research at the 1991 National Educational Computing Conference (NECC) in Phoenix. Nine of the papers from that conference have been included in this monograph. The preface is by Dr. Andrew Molnar of the National Science Foundation, who served as an overall discussant for the presentations.

New Research Paradigms: Collaborative Partnerships

Until rather recently, educational research has been primarily the domain of professional researchers (scholars who reside in universities and who hold doctorates and research credentials) rather than of practitioners holding teaching positions in the field. There is a separation between the development of theory and practice, to the detriment of both researchers and practitioners. Historically, much educational research has sought to develop generalized knowledge and has not been heavily concerned with the particularity of settings. Traditionally, research has been used to influence policy, not practice, while teachers have influenced pupils, not policy.

Computer-using educators are particularly challenged by the need to create new educational approaches and to interpret their practices. Logo offers an interesting case in point. Much of the academic research on Logo learning has focused on broad questions—for example, "Does Logo support the learning of problem-solving skills?"—without considering the particular classroom contexts. Perhaps for this reason, most research of this sort has generally been inconclusive about the benefits of Logo. However, many observers have concluded that complex variables, such as the way Logo is taught, the teachers' and students' knowledge, and the particular curriculum used, are all major factors influencing learning.

Teachers incorporating Logo (or any innovation) into their practices must resolve a series of complex issues. Classroom research is one way for teachers to make informed teaching decisions. Because documenting practice may be an add-on to teaching, collaborative partnerships are useful for sharing the work involved in carrying out the studies. More substantively, collaboration ensures a triangulation of perspective. The research methods used should be unobtrusive and not in conflict with teaching. The research agendas should support the classroom teacher's learning goals and the students' learning needs. The research agenda should contribute to the knowledge base of other participants in the field.

We believe that the articles in this monograph and the research processes that they describe support these lofty as well as practical ideals. The form of collaboration among teachers and other researchers and the methodologies used are as important to the future of classroom research on Logo learning as the research findings themselves.

Several approaches to collaboration are represented in this volume. Warren Toth, a classroom teacher, and Dale Burnett, a university professor, studied their process in collaborating while studying the kinds of Logo projects developed by Toth's students in grades four through six. Karin Wiburg, a university researcher, and María Fernández, a classroom teacher, designed and carried out a formal study in collaboration with several other fourth-grade teachers. Irene Hall, a classroom teacher, and Paula Hooper, a university researcher, met at a summer institute and created a research collaboration on curriculum development undertaken while teaching a course for seven- and eight-year-old children and their parents in a science museum.

Four of the authors are participants in the Logo Action Research Collaborative (LARC), a national pilot project funded by the National Science Foundation (NSF) to support teacher-facilitated collaborative action research groups. Donna Cutler-Landsman, a member of the Madison, Wisconsin, LARC group, is a classroom teacher who investigated how to bridge the gender gap in her sixth-grade classes. She collaborated with her students in addressing this issue. Nan Youngerman is the teacher facilitator of the Madison LARC group, which met throughout a school year to share their ongoing research process on Logo learning.

Patricia Rowe, of the Boston, Massachusetts, LARC group, is a middle school teacher who reflected on her experiences in using Logo as a vehicle to help underachieving students develop self-esteem and cooperative learning skills. Donna Rosenberg, also a Boston teacher, challenged herself and her fourth-grade class to develop understandings with variable inputs. These teachers' action research, carried out with the help of their LARC colleagues, supported them in their efforts to link research investigations with beneficial changes in their instruction.

Two other articles by university-based researchers serve to highlight the role of the teacher as researcher. Karen Swan worked as a teacher-researcher with a group of fourth- and fifth-grade students. She used qualitative methods to investigate the diverse ways her students approached Logo problem solving. Jim Dunne sets a framework for these recent classroom-practitioner and collaborative approaches to Logo research. He reviews the previous generation of Logo research studies in order to demonstrate the need for Logo research that is situated in classrooms and focuses broadly on the development of cultures of learning.

Focus of the Studies

As editors, we have grouped the articles that follow into clusters, according to what we believe is the main focus of the authors' concerns. In the sections that follow, we briefly summarize these articles to bring out their common themes and, we hope, whet the reader's appetite for the articles themselves.

The first set of five articles deals primarily with understanding the cognitive outcomes of Logo learning for the purpose of enhancing that learning. The authors grapple with issues related to understanding the mathematical and computer science ideas, as well as the creativity and problem-solving strategies their students are learning.

The second set of articles focuses on the social context of Logo learning. The authors are trying to understand who their students are as socially related learners, how they collaborate with each other, and what they bring with them to class as a result of prior socialization. The ultimate goal is to improve the learning experience for all learners in the classroom by intervening in the ways students interact with each other and perceive themselves as collaborators in a learning culture.

The final two articles focus on the collaborative research process itself. They show how a university/classroom collaboration and a collaborative network of teachers can lead to benefits for teachers' professional growth and confidence, and ultimately to their students' learning of Logo.

Cognitive Outcomes of Logo Learning

1. Making a Case for the Learning Culture as the Focus of Classroom Research on Logo by Jim Dunne, Long Island University, C. W. Post Campus

Dunne's article begins with a historical review of several major research projects involving Logo environments during the late 1970s and early 1980s. In Dunne's view, the early Logo research "for the most part focused on the effectiveness of programming as a vehicle for the development of higher order skills," but he noted that there were somewhat disappointing results when studies focused narrowly upon technical programming skills. He therefore suggests that to gain the most benefit from Logo, teachers and researchers should concentrate more on understanding the social learning cultures in classrooms in order to support learning partnerships between students and teachers. He concludes that for Logo to deliver its full potential, teachers need to develop environments in which there is a constructivist framework for children's learning. The learners should explore extended projects and share knowledge with peers. Teachers should be knowledgeable in programming and pedagogy and act as guides. Dunne suggests that a powerful means for supporting the transition to this type of pedagogy is action research by teacher-researchers.

2. Domain Knowledge, Cognitive Styles, and Problem Solving: A Qualitative Study of Student Approaches to Logo Programming by Karen Swan, State University of New York at Albany

Karen Swan has investigated the learning of problem solving in a Logo context for several years. Although Swan's earlier research demonstrated that "a particular kind of Logo-based problem-solving intervention could support the development of specific problem-solving strategies," she felt that it did not reveal how, why, or precisely what the students were doing that caused increases in their problem-solving abilities. This particular study of 11 fourth and fifth graders Swan taught focuses on the problem-solving strategies individual students bring to and utilize within Logo programming contexts. Swan's study shows how such strategies are affected by the student's domain knowledge and cognitive style. It was undertaken in the belief that students bring unique personal knowledge to their school experiences and that a small, systematic investigation of Logo problem solving might lead to insights into the diversity of ways in which students approach and organize their problem-solving skills.

Using qualitative research methods, Swan noticed the emergence in her data of the pairing of certain problem-solving strategies with specific cognitive styles and/or domain knowledge. For instance, the problem-solving strategy of subgoals formulation seemed to be linked with combined global abstract cognitive styles. Similarly, forward chaining seemed to be linked with combined local and concrete cognitive styles; systematic trial and error seemed to be linked to good domain knowledge of Logo; alternative representation seemed to be linked to a lack of domain knowledge; and problem solving by analogy seemed to be linked to abstract thinking.

3. Creating a Successful Learning Environment With Second and Third Graders, Their Parents, and LEGO/Logo by Irene Hall, Lawrence Public Schools, Lawrence, Massachusetts; and Paula Hooper, Massachusetts Institute of Technology

This article describes the efforts of two collaborating teacher-researchers in developing and revising a LEGO TC Logo curriculum for seven- and eight-year-old students and their parents at the Boston Museum of Science. The teachers gathered data and revised their course to better meet children's interests, skills, knowledge levels, and learning needs. Both courses focused on using LEGO TC Logo to create kinetic art and on fostering a creative, exploratory atmosphere. The researchers asked themselves: "What are the essential *primitives*, or building blocks, that allow students to embellish creatively while learning to powerfully use a particular system without receiving extensive background?"

The first version of the course took an open-ended approach, encouraging children and their parents to work on long-term projects. However, the researchers reported that the results were disappointing: "We observed that focusing on the notion of art left the specifics of how to create movements at too complex a level for the students to discover for themselves." In revising the course for its second run-through, Hall and Hooper developed a series of small working models for participants to use as primitive elements or building blocks. Each model embodied a different approach to producing motion, for example, beveled gears showing transfer of motion at right angles, mounting an axle so that it spins freely, and connecting gears "off-center for *lopsided* or up and down motion." In addition, Hall and Hooper restructured their five-session course so that each session introduced one new idea, and ended with the sharing of projects in a kinetic art show.

The new course structure, along with the specific models, allowed students to successfully incorporate fresh ideas each time, rather than work on one long-term project. Instead of introducing concepts didactically, step-by-step, on the one hand, or allowing totally free exploration on the other, the authors found that providing primitive building blocks or models allowed the children to "become aware of ideas that [support them in] creating the projects they envision."

4. Researching for Effective Strategies of Teaching Variables to a Fourth-Grade Logo Class by Donna Rosenberg, Patrick Kennedy Elementary School, Boston, Massachusetts

Rosenberg, quoting Papert on the notion that "a variable is one of the most powerful mathematical ideas ever invented," challenged herself to teach the power and concept of a Logo variable to a fourth-grade class. Her research questions focused on an analysis of teacher intervention strategies to foster such learning. Rosenberg was particularly interested in helping her students realize the power of the computer as a tool for analyzing and solving problems.

Much of Rosenberg's article illustrates how a series of seemingly simple projects (for example, building a group of squares of different sizes) can provide a rich context for the observation of "a wide variety of student approaches." This variety was particularly evident as students moved from immediate mode responses to the use of a procedure with variable input. Rosenberg encouraged her students to share their partial solutions or variations of procedure plans through formal sharing times and informal exchanges with each other. This supported some students in using other students' codes and in elaborating on someone else's discovery.

As the challenges increased in complexity, Rosenberg observed that one of her most successful strategies was the insistence that her students plan their programs in English in addition to developing Logo code. Her article documents her observation that in addition to achieving some success in using variable inputs, her students also engaged in developing theories, posing questions, and setting challenges for each other.

***5. The Effect of One Logo Learning Environment on Students' Cognitive Abilities** by Karin M. Wiburg, San Diego County Office of Education, and María Fernández, U. S. International University, San Diego, California*

Wiburg, a university-based researcher, and Fernández, then a classroom teacher, collaborated with fourth-grade teachers in San Diego in planning and carrying out a study whose purpose was to learn about the cognitive benefits that they felt their students were gaining from Logo. As they noted, "We believed that programming had positively impacted our own thinking as well as the thinking of the students we had worked with, yet we were challenged by the lack of research data to support our beliefs. We were determined to look more systematically at what seemed to be working well in the Logo classes at Park Dale Lane Elementary School."

Wiburg, Fernández, and the teachers at the elementary school chose a social studies context in which students could learn computer programming and problem solving while applying their knowledge to a content area in the school curriculum. The students as problem solvers learned to organize information about the Gold Rush, think divergently about the miners' environments, and use brainstorming techniques to find solutions to problems the miners faced.

In addition to involving a Logo group, the research involved two other treatment groups: a second experimental group in which problem solving was taught in conjunction with the writing process and word-processing software and a control group that worked with computer application software and "quality CAI software."

At the end of the study, students in both experimental groups made significantly higher gains than did the control group on the higher level thinking components of a cognitive test. In addition, evaluation of student products by English teachers indicated similar levels of coherence of the messages produced by both experimental groups, but the products of the *LogoWriter* students were judged to be significantly more creative than those of the students who used word processing.

Logo Learning in a Social Context

6. Bridging the Gender Gap With LEGO TC Logo by Donna Cutler-Landsman, Elm Lawn Elementary School, Madison, Wisconsin

Cutler-Landsman's article starts by stating that "numerous studies have indicated that boys score higher than girls on science achievement tests. This is one factor that has lead to an imbalance in the numbers of women as opposed to men in upper-level science courses and has discouraged girls from pursuing careers in engineering, physics, earth sciences, and chemistry." As a first step in attempting to address such an imbalance in her own classroom, she identifies an explanatory hypothesis: Boys may have done more tinkering than girls and therefore have a more positive attitude toward science and technology.

Her action research addressed this issue by using LEGO TC Logo to encourage girls to develop tinkering skills. She studied the relationship of gender to motivation, willingness to diverge from projects presented in the manual, experimentation to improve performance of a mechanism, and the types of projects the students completed.

Cutler-Landsman reports that "after the novelty with LEGO building wore off, it was apparent that most boys were interested in building increasingly complex projects and that most girls were rapidly losing interest in the entire project." The girls worked on beginning projects, sticking closely to the manual, while the boys experimented with "unique and complicated inventions."

As an action researcher, Cutler-Landsman decided to make an intervention. She required mixed-gender groupings. She limited the choice of projects to simple projects that involved programming rather than manual manipulations of LEGO bricks. She assigned girls specific roles as keyboarders or reporters to support active participation. Cutler-Landsman concluded that mixed-gender groupings and defined roles for group members worked positively: "The boys were still more adept at building the models, but many girls gained more confidence and went on to work independently on building their own vehicles."

7. Increasing Cooperative Behaviors in an Urban Middle School Classroom by Patricia Rowe, Thompson Middle School, Boston, Massachusetts

Rowe's article focuses on her attempts to create a more effective learning atmosphere with a group of inner-city middle school students whose approach to learning was deeply influenced by the social context of violence in the neighborhoods around the school. She hoped that a Logo learning experience would empower her students to develop greater self-esteem and to realize the benefits of collaborative learning.

Rowe frequently observed student behaviors that she characterized as "verbal hostility and ... physical confrontations." Her key learning goals for her students therefore included expectations that they would learn to talk to each other constructively, respect each other as resources of knowledge and skills, and work together effectively in pairs on extended projects.

As part of her action research cycle, Rowe devised strategies to encourage students to work cooperatively and to reflect on their behaviors. She kept a journal of daily reflections, compared the projects of different students to trace the sharing of ideas among them, interviewed students about their attitudes toward helping and being helped, and compared these interviews with her own observations of such behavior.

From interviews and observational data, Rowe concluded that almost all students came to regard helping and being helped as positive elements of learning. This was a marked shift from her earlier observations. When reflecting on their particular learning, these students tended to remember when they helped others but not when others helped them. She concluded that there was more work to be done in building a culture of cooperation where both "seeking and giving assistance are valued."

8. A Magnifying Glass Has Two Sides: Observing the Effects of Collaborating on Two Research Collaborators *by J. Dale Burnett, University of Lethbridge, Alberta, Canada, and Warren Toth, Eastridge Elementary School, Cardston, Alberta, Canada*

This article describes an ongoing informal collaboration between J. Dale Burnett, a university professor, and Warren Toth, an elementary school teacher. From the outset, they decided the partnership would be equal. One goal of the study was to examine student learning by drawing on their dual perspectives. Their second goal was to observe their collaborative process. "The hypothesis is that much of the impact of a research study is not only in what the researcher notices but in what the teacher notices as a result of being noticed," they explain.

Their action-research process starts with a visit by the university observer who makes notes about what he sees. This is then discussed with the teacher. A cyclical process ensues, consisting of several phases: Action, Shared Observation and Questioning, Reflection, and Change in Perception and New Ideas. As a classroom teacher, Toth states, "For me, the real power of the project has been in the action phase of the study. ... Discussing this study, a fellow teacher stated, 'It will be nice to apply what you've learned when it's all done.' However, because of the nature of this study, change has already been actualized! Application has already taken place, and will continue, and that is what makes this process so powerful and exciting for me as a teacher."

Burnett was concerned with the immediate local impact of a collaborative research project. Commenting on the teacher's response, he observes that Toth "echoes at a pedagogical level the same messages that have been heard at the student level: It is encouraging to have someone show confidence in your abilities, it is important to have ownership in your ideas, it is comforting to have a *guide on the side* when you want one."

9. An Action Research Collaborative From A Leader's Perspective by *Nan Youngerman, Crestwood Elementary School, Madison, Wisconsin*

Youngerman's article describes and evaluates the first year of the Madison Logo Action Research Collaborative (MLARC) in Madison, Wisconsin. She points out that Madison was already a "supportive setting for action research" because of the university leadership of Bob Tabachnick and Ken Zeichner, four prior action-research groups, and a concurrent multicultural action-research group. She reports that "the purpose of the group was to support experienced teachers in critically examining their practices; engaging in collegial reflection and dialogue; increasing their knowledge of Logo; developing methods for assessing student learning; carrying out an action research project; revising, improving, or developing their teaching practices; developing more authoritative professional voices; and participating in peer support to research by colleagues." One of the support strategies Youngerman devised was inviting more experienced action researchers to be guests of the group at critical phases.

The group was composed of 11 teachers, Youngerman explains, and more than 500 students benefited. She reports on the benefits for teachers in terms of the ways they revised their teaching practices. Teachers became more interested in exploration: there was "less looking at products mastered, less worry about curriculum coverage," she says. She also summarizes the importance of the process to herself: "I felt a sense of professional empowerment thinking with other researchers about the important questions facing education today, how we investigate them, and what support systems would benefit us most."

Summary Comments

When, as in the case of this small miniconference, there is an opportunity for the teachers and the researchers to share their findings and methodologies, the researchers and teachers may inspire others to try their hand at this kind of action research. The research would indicate to others whether the research findings presented here are true for their own students and whether the same strategies can be implemented in their own classrooms. However, action research might be designed to answer their own questions. By presenting the results of their work on a national level, professional educators have an opportunity to exchange agendas and insights while participating in a common community of inquiry. Teachers who observe carefully in individual classrooms may find that they have grounded knowledge to share with policy makers.

We can imagine a time when there will be many such small studies of particular Logo learning situations and the contexts that support them. We encourage educators who conduct small, classroom research studies to submit proposals to hold miniconferences in conjunction with national professional meetings and thus contribute to the profession, pedagogy, and policy. For the educational researchers who presented at NECC in 1991, the publication of this monograph is not the end of the research study. Each researcher has begun to investigate a new question at a deeper level.

Making a Case for the Learning Culture as the Focus of Classroom Research on Logo

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Abstract

This article describes how Logo has been interpreted and outlines some major research efforts conducted to assess the effectiveness of Logo. It explores the issues and controversies generated by these studies, and it explains the disparities in the research findings as a factor of how researchers interpret and implement Logo and the learning environment it is intended to be a part of. It also outlines key aspects of a Logo learning culture and is based on a review of the literature on programming, Logo, cognition, problem solving, and educational change. The culture is described both in terms of what is necessary to create the learning environment (institutional support, material resources, curriculum, and interpersonal relationships), and the knowledge, skills, and methods needed by Logo teachers. Teacher-researchers can use this outline to assess the extent to which the Logo programming/learning cultures that they create are likely to bring about significant cognitive change in their students.

Introduction

The child-centered, exploratory nature of Logo exists in opposition to the organizational structure and belief systems of most schools. Research on Logo and Logo-like programming environments has, for the most part, focused on the effectiveness of programming as a vehicle for the development of higher order thinking skills. To date, the major benefit of this research has been to help both researchers and practitioners realize that there is no simple answer to the question of Logo's effectiveness. The research has also helped to clarify some major issues and misconceptions, and has indicated that programming can be an effective cognitive tool when defined and implemented in specific ways. Yet Logo research has been limited by Seymour Papert's notion of *technocentricity*. Most studies have focused on the *new technology* without adequately dealing with all of the other elements that make up the total learning culture. Given the logistical nightmare of attending to all of the variables in a complex learning environment, it seems unlikely that the question "Does Logo work?" will ever be definitely answered through experimental research. However, research has provided some insight into what the characteristics of a successful programming environment might be. Unfortunately, new problems and issues arise when the research is moved from an experimental context into the day-to-day school culture.

Many of the problems associated with Logo since its introduction in schools can be traced to the difficulty of easily and precisely defining it. Most early interpretations were relatively simplistic and rarely addressed the complexity of the technology or of the related pedagogy. Initially, most schools and researchers opted to view it as a relatively straightforward delivery system.

The lack of a commonly accepted interpretation or definition of Logo has been a real impediment to successful implementations in most schools. Ideally, when interpreted as the focus of a complex learning environment or culture, Logo can be defined as a

> high level computer programming language that has its roots in the constructivist theories of Jean Piaget, and in the need to better understand our own thought processes taken from the field of Artificial Intelligence. It was designed to provide children with an environment that is rich in interesting things to do and to think about. In the process of learning and using Logo, children are thought to develop higher order logical/mathematical skills that are applicable to a much broader range of tasks than just programming. These skills are developed during a child's intrinsically motivated explorations of Logo microworlds. These explorations require the child/programmer to engage in self-reflective behaviors that will lead to a better understanding of, and control over, their own thought processes. (Dunne, 1991a)

In his analysis of Logo use in schools, Becker (1987) noted that while many Logo teachers say they understand and advocate a *Logo philosophy*, "the actual classroom practices of these teachers is not as distinguishable from other computer-using teachers as their ideas about the value of using computers. Many, if not most, classrooms that use Logo appear to be rather traditional environments" (p. 12). It seems that while many schools have bought into the educational promise of Logo, they haven't made the investment in curriculum development, time, training, and equipment that is required to achieve the promise.

Interpreting Logo

Logo has often been interpreted as a type of learning that has the child interacting with the computer and the programming language without the intervention of a human expert. The expectation is that the child will develop problem-solving skills that will eventually transfer to situations other than programming. This interpretation is usually attributed to Seymour Papert's (1980) book *Mindstorms: Children, Computers and Powerful Ideas*, and is revealed in such quotes as "Logo programming assumes that students will spontaneously develop generalizations" (Pogrow, 1985, p. 28), or "Logo instructional experiences typically have not included any attempt to explicitly teach students in the use of these [higher order] skills" (Krasnor & Mitterer, 1984, p. 135). Probably the most critical and influential interpretation of Logo as a treatment that will deliver higher order skills is found in research done at the Bank Street College of Education. Pea and Kurland's (1984a) major criticism was that

> the Logo instructional environment that Papert offers to educators is devoid of curriculum, and lacks an account of how the technology can be used as a tool

to stimulate students' thinking about such powerful ideas as planning and problem decomposition. Teachers are told not to teach, but are not told what to substitute for teaching. (p. 44)

Early Research on Logo

Pea and Kurland (1984a) reacted to what they saw as the lack of any real empirical evidence to prove that Logo actually does improve higher order thinking skills. They were alarmed by the widespread adoption of Logo by schools and believed that it was being accepted based on *technoromantic* claims that had intuitive appeal but that lacked verification. They noted that the major study on Logo up to that point was anecdotal. While it provided a positive model of what Logo could do, it did not validate Logo's effectiveness.

The Brookline Project

The study known as the *Brookline Project*, (Papert, Watt, DiSessa, & Weir, 1979; Watt, 1979) was carried out by the MIT Artificial Intelligence Laboratory under the direction of Seymour Papert. The Brookline Project was the first attempt by the developers of Logo to move it out of the laboratory and into a school setting. Its main focus was to provide case studies that would describe the experience that 16 students of various backgrounds, ability levels, and ages had while learning with Logo. While the study was conducted in the Brookline Massachusetts schools, it was taught primarily by MIT staff in small-group and individualized settings over a one-year period. The research methodology included interviews of both students and teachers (before, during, and after the Logo experience), structured and unstructured observations of the students at work, teacher anecdotal records, and detailed analysis of both the written and computer work of the students. The case studies that emerged illustrated that the Logo experience had, to varying degrees, a positive and in some cases very powerful effect on the students. They were intended to serve as models of how a Logo experience could affect a variety of student types. The researchers believed that these student types would be familiar to most educators. The case studies also served as a model of how the students interacted with their teachers and peers, learning materials, and environment.

Bank Street

After the Brookline Project, there was a growing call for more systematic and less anecdotal research on Logo (e.g., Pea, 1983; Pea & Kurland, 1984a, 1984b; Ginther & Williamson, 1985). The Bank Street researchers set a primary agenda to determine if computer programming promotes the development of higher mental functions. Their initial study was carried out at the Bank Street School with 32 children ranging in age from 9 to 12 years. Instruction was provided by Bank Street teachers in two weekly sessions over 15 weeks, for a total of 30 hours of exposure. Their method was quantitative in that it consisted of giving pretests and posttests to groups that received Logo as a treatment, and to control groups that received a drill-and-practice CAI program. They designed the Logo treatment to reflect what they believed to be a realistic classroom implementation.

There was only one knowledgeable, but not expert, teacher per class. Their stated strategy was to provide the students with the hardware and software, and to assume that knowledge acquisition will come from self-guided problem-solving experiences, with no deliberate or organized teaching. The study was specifically searching for a transfer of planning skills from Logo to other areas. The task they developed to evaluate this in the pretests and posttests had the students describe how they would go about cleaning their rooms. They found no significant difference in the planning ability between the Logo group and the control group. Two later studies, using a slightly more directive teaching strategy, also failed to show any significant cognitive gain by Logo users.

The Bank Street research had a profound impact on the acceptance and the continued use of Logo in many schools. For example, Tetenbaum and Mulkeen (1984) suggested that, based on the Bank Street findings of no cognitive gains, a moratorium be placed on Logo implementation in schools until research is carried out to demonstrate that it leads to the cognitive gains claimed by its developers. Both the school and the research community (e.g., Mayer, Dyck, & Vilberg, 1986) often cite the Bank Street research as proof that neither Logo in particular nor programming in general leads to the development of higher order skills.

There have been two main lines of criticism of the Bank Street research. The first is that there was a mismatch of treatment and transfer assessment. The researchers were looking for high-level cognitive transfer outcomes that could be expected to occur if students engaged in planning activity during their programming time. However, the level of programming the students achieved after their brief exposure was relatively low. Their programming was still centered on learning the syntax and semantics of the language. They were not given instruction in, or models of, planning during their Logo experience. In addition, the students were never shown how their Logo experience might be connected to the task of planning a room-cleaning strategy. Because planning activities weren't an explicit part of the teaching strategy and the students didn't engage in planning activities during the treatment, there was little reason to expect that they would show any improvement on the posttest. As suggested by Kinzer, Littlefield, Delclos, and Bransford (1985), "the general findings of no significant transfer may be due to inadequate mastery of Logo rather than a lack of transfer effect" (p. 42). Groen's (1984) description of the other major problem with the Bank Street research was that "it ignores the possibility that the kinds of tasks a student programs and the teaching method that is used may affect the outcome of a student's interaction with Logo" (p. 50). In other words, Bank Street interpreted Logo as a system that would deliver higher order skills regardless of the context in which it is used.

Clements

Research by Douglas Clements and his colleagues (Clements & Gullo, 1984; Clements, 1985, 1986, 1987) was conducted using a quantitative approach similar to the Bank Street project, but they arrived at very different conclusions. The divergence can be attributed to two major differences in conception and design of the research method.

First, Clements used well-known standardized tests of cognitive function designed to measure a broad spectrum of cognitive behavior, as opposed to the locally developed and narrowly defined test used at Bank Street. Second, their Logo treatment was less restrictive. Instead of trying to model a *typical* classroom, the children worked in small groups with adequate computer resources and had the support of knowledgeable teachers. The studies showed that the Logo groups tested higher on assessments of creativity, on measures of reflectivity and divergent thinking, on comprehension monitoring, and on the ability to describe directions. Clements (1986) notes that findings of no difference on measures of reflectivity conflicted with earlier research (Clements & Gullo, 1984). He believes that a difference in treatments could account for the discrepancy. The latter study "incorporated proportionally less direct teaching and more independent work by the children" (p. 316). He hypothesizes that without some structure and appropriate models the students' problem-solving strategy of choice will be impulsive trial and error. The researchers also cited evidence to indicate that the benefits hold up over time.

In describing the discrepancies between the Bank Street findings and Kent State's findings, Becker (1987) notes that it is possible to account for the differences in the results by the more active role of the teacher and the environment in the Clements studies. He does, however, believe that Bank Street is actually a better measure of what would happen in a typical classroom.

Research by Reiber (1987) also supports the claims for the cognitive benefits of Logo. This study found that a group of children who used Logo performed better on measures of problem solving than did a group with no Logo exposure. He speculated that the difference between his results and Bank Street's results lies in the interpretation of the learning environment in which the Logo programming took place. The Logo environment described in the Reiber study consisted of a mixture of direct teaching, guided discovery "where the teacher played an important role in the learning paths taken by students" (p. 15), and free discovery where students had "ample time and freedom to experiment with the Logo microworlds" (p. 15). Reiber concludes that "Logo's success is heavily dependent on the learning environment" (p. 15).

Responses to the Early Logo Research

Papert (1985) has been encouraged by the favorable research, but cautions that he will

> be rather surprised (though pleasantly so) if the cognitive changes measured by Clements and Gullo turned out to be repeatable for all children with all encounters with Logo ... but ... perhaps it will lead to recommendations about how to design Logo environments so that most children would experience the developments it reports. (p. 62)

Papert (1985) believes that all Logo research, both positive and negative, that takes a treatment approach is flawed because it demonstrates an inadequate recognition of the fact that what the research is looking at and making decisions about "is not programming but cultures that happen to have in common the presence of a computer and the Logo language" (p. 62).

Papert (1985) equates the emphasis usually placed on the language itself with what he sees as a fundamentally flawed view that many educators and researchers have of technology. He believes that when educators pose such questions as "What is *the* effect of the computer on cognitive development?" or "Does Logo work?" they

> betray a tendency to think of "computers" and of "logo" as agents that act directly on thinking and learning ... [and also] ... betray a tendency to reduce what are really the most important components of educational situations—people and cultures—to a secondary, facilitating role. (p. 54)

From this perspective educators should not view programming or Logo as free-standing educational packages that will deliver specific goals or knowledge. Papert (1985) believes that children encounter programming in Logo "in a particular way, in a particular relationship to other people, teachers, peers, mentors and friends. They don't encounter a thing, they encounter a culture" (p. 62). This approach to programming views computers and programming languages as part of a larger culture. Their presence may have a significant effect on the learning and thinking of those involved with that culture, but to understand or have an effect on that culture one needs to focus on the culture as a whole, not just any one individual part. In Papert's view, the context of human development is always a culture, never an isolated technology. From this perspective, the computer and the programming language are just part of a much larger web of mutually supporting and interacting processes that make up a Logo learning culture. Papert believes that it is just not feasible to isolate these factors one by one and study all the possible combinations of situations in order to evaluate their effectiveness.

In reply's to this position, Becker (1987), Pea (1987), and Walker (1987) generally agree that much of the initial research on Logo has been flawed. They agree that it is unfair to judge something that is as complex as a Logo culture on the basis of group means and narrowly defined outcomes. They also agree that policy decisions on the use of an innovation should not be based on the results of a few limited early studies. They do assert, however, that Papert's claims about Logo are vague and that his call for case study research will not produce generalizable results. They believe that research that can be replicated and generalized needs to be carried out to determine the characteristics of effective Logo environments, and until this happens, the widespread adoption of Logo should not be encouraged.

Defining Logo Culture

It seems that the major roadblock to date in interpreting, researching, and implementing Logo has been in coming to an understanding of what actually makes up a Logo culture. Gallini (1985) stated that much of the criticism of Logo is unfair, but acknowledges that it is based on unclear and unfounded claims made for it in much of the literature. When Logo was first being introduced into schools, Groen (1981) acknowledged that "the literature on Logo as it currently exists does not provide a specific rationale or a clear set of goals. While it is a perfectly defined environment, it is currently unclear what should be done with it" (p. 307).

In assessing why Logo has failed to meet the expectations of many of its early users, Weir (1987) states that

> Logo is not to be viewed as some patent medicine, good for everything regardless. Nor will its benefits emerge as an automatic consequence of its use. Unfortunately, an impression was gained from the early descriptions of Logo that putting the child together with a computer equipped with Logo was all that was required. (p. 10)

Solomon (1986) claims that this was not Papert's intention. Logo is described as providing the environment or culture in which the teacher (expert) and the student (novice) can find common ground to discuss their projects (goals) and the problems (bugs) they encounter, and how to identify and build on the knowledge they will need to accomplish their goals. In addition to helping to structure the environment so that the children avoid unprofitable or unnecessarily frustrating paths, the teachers also learn about their students, themselves, and the content they are exploring.

The loudest message that has emerged from all the research on Logo (both qualitative and quantitative, positive and negative) is that if Logo is interpreted as a stand-alone program that will deliver cognitive gains, disappointment will follow. However, if Logo is treated as an element of a larger learning environment, significant cognitive benefits may result.

At the same time, it is important to understand that the reasons schools may have for implementing programming or Logo can be quite different. Heller (1986) points out that "different learning environments yield different educational outcomes ... [and that] ... before choosing a Logo environment it is crucial to determine a set of educational goals" (p. 125). It is also crucial to design an educational program, environment, or culture that will be necessary to achieve those goals. The reason that most schools have not been able to achieve their often-stated goal of helping children develop higher order skills through the process of programming seems to be that they have not understood what they need to do beyond introducing their students to the mechanics of programming. Without the associated learning environment, Logo is just technical knowledge.

It seems unlikely that Logo's promise will be achieved until a number of models of how to implement a Logo environment in the classroom are developed and disseminated.

A Focus for Classroom Action Research

Many of the underlying issues, themes, and approaches associated with Logo are closely linked to old struggles over the nature of learning, the purpose of schooling, and the role of teaching. The history of education and the literature of educational change indicates that it is unlikely that an innovation or reform such as Logo will succeed when it conflicts with the prevailing beliefs and organizational structure of schools.

Creating a programming culture capable of fostering the development of higher order thinking will require material, organizational, social, curricular, and behavioral changes in the classroom. Based on a review of the literature on programming, Logo, cognition, problem solving, and educational change, Dunne (1990, 1991a, 1991b) has identified key aspects of this type of Logo learning culture. In general, classroom researchers seeking successful implementations of Logo will need to address how well Logo learning cultures demonstrate

- a developmental/constructivist framework based on the belief that children need to build their own intellectual structures
- an activity-based curriculum, in part, directed by the self-motivated and self-guided explorations of the learner
- a learning culture rich in material and human resources and governed by democratic classroom processes
- an emphasis in the development of higher order thinking skills
- a view of the teacher as a guide and the student as a self-activated and self-directed natural learner

In particular, they will need to focus on whether

- Students are provided with enough access to computers to meet curricular goals.
- Students possess a basic mastery of the syntax and semantics of Logo so that they can use programming as a creative and exploratory tool.
- There is a large enough time commitment for programming instruction so that students can become engaged in extended projects.
- Students are provided with models of effective programming and problem-solving strategies.
- Students are given the freedom to both devise their own problems and explore various paths to a solution.
- Students are provided with the opportunity to work individually, in pairs, and in small groups.
- There is an emphasis on the development of a vocabulary to express the ideas and problems students and teachers encounter while programming.
- Teachers are encouraged and are provided with the opportunity to become expert programmers.
- Teachers understand and incorporate the theory and the pedagogy behind using programming as a vehicle to develop higher order thinking skills.
- Teachers teach for transfer so that they demonstrate how solving programming problems can relate to a much broader range of problems and subjects.

- There is continuity of programming instruction throughout the grades.
- There are methods of evaluation and assessment that focus on identifying student needs in order to provide them with appropriate help and resources.

Conclusion

It is obvious that most schools lack the ability, the resources, or the will to implement and sustain learning cultures that display these characteristics. It also seems clear that the widespread implementation of this type of programming culture will not occur without the fundamental restructuring of the ways in which schools are currently being organized and run.

There are strong indications that when the focus of programming instruction is on the learning culture, not just the isolated aspects of it, cognitive gains will be realized. But creating and sustaining a flexible, child-centered, and exploratory learning culture requires fundamental changes in almost all aspects of school organization and operation. In essence, the successful implementation of a Logo programming culture would require a total restructuring, or cultural transformation, within most classrooms. Because of this, Logo in particular, and programming in general, face the real danger of being relegated to the scrap heap of educational innovations that promised much but delivered little.

The current movement calling for a restructuring of schools and a focus on developing independent creative thinkers may create a more hospitable climate for Logo-like programming environments. Classroom action research that focuses on the total programming/learning culture will provide implementation models that can help to guarantee the fruitful survival of Logo.

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Domain Knowledge, Cognitive Styles, and Problem Solving: A Qualitative Study of Student Approaches to Logo Programming

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Abstract

This article describes a qualitative study of the problem-solving strategies used by 11 fourth- and fifth-grade students in solving simple Logo programming problems, and of relationships between those strategies and students' domain knowledge and cognitive styles. The study employed a modified clinical interview methodology that integrated talk-aloud protocols with transcripts of the programming commands students used in solving the problems to examine such relationships in light of both developmental and dispositional explanations of differences in problem-solving behaviors. Findings support the existence of a diversity of cognitive styles, at least among the age-group studied. The findings also relate cognitive styles to problem-solving strategies and suggest a knowledge-based explanation for differences in problem-solving behaviors. The results of the study demonstrate the efficacy of the methodology employed.

Background

The Logo programming language was designed to support students' construction of knowledge about mathematics, problem-solving, and elementary computer science (Papert, 1980). A decade of Logo use in the classroom has led to a body of research that suggests that Logo-based instruction can support students' development of specific mathematical understandings (Lehrer, Sancilio, & Randle, 1989; Thompson & Wang, 1988), problem-solving strategies (Carver & Klahr, 1986; Swan, 1990), and computer science concepts (DeCorte, Verschaffel, & Schrooten, 1989), when those topics are explicitly taught. Nonetheless, many questions remain unanswered regarding the ways in which individual students construct knowledge within Logo environments and the ways such constructions can be supported, expanded, and developed. These questions deserve systematic exploration.

The study reported in this article grew out of several years of quantitative research concerned with the development of effective Logo-based interventions for the teaching and learning of problem solving (Swan, 1989, 1990; Swan & Black, 1989). Although that body of work successfully demonstrated that a particular kind of Logo-based problem-solving intervention could support the development of specific problem-solving strategies, it revealed little of what individual students were doing that caused positive increases in their problem-solving abilities, and it did not address the problem-solving strategies those students brought to the intervention.

The investigation reported in this article represents a preliminary step in the latter direction. The investigation concerned itself with the problem-solving strategies individual students bring to and utilize within Logo programming contexts and with how such strategies are related to students' domain knowledge and cognitive styles. The belief that students bring unique, personal knowledge and practices to their school experiences guided this investigation, along with the belief that a systematic investigation of a small part of that experience within the constrained and reflective domain of Logo problem-solving might yield insights into the diversity of ways in which students approach and organize their problem-solving activities.

In particular, this study explores two differing explanations for the diversity found in problem-solving behaviors: (a) the developmental explanation (Ginsburg & Opper, 1980; Piaget, 1971), which holds that such diversity represents evolutionary stages through which people naturally pass as they develop mature problem-solving behaviors, and (b) the dispositional explanation (Turkle & Papert, 1990), which argues that such diversity represents mature "cognitive styles" that are equally valid on their own terms. In so doing, the study develops a methodology based on the traditional Piagetian clinical interview and proposes a third possible explanation, based on domain knowledge, for the diversity of observed problem-solving behaviors.

Methodology

Programming in Logo is uniquely suited to students' reflections on their own thinking and problem-solving because the programming process involves both the symbolic representation of step-by-step solutions and the dynamic testing and refinement of those solutions. As Turkle and Papert (1990) note, the computational object is "on the border between an abstract idea and a concrete physical object." This article takes the similar position that because a correspondence can be drawn between the thought processes of student programmers and the programming commands they use to solve particular problems, Logo programming might be an ideal environment for the investigation of children's problem-solving strategies.

The methodology used here, then, is a variation on the traditional Piagetian clinical interview (Ginsburg & Opper, 1980). The participating students were asked to solve Logo programming problems, and their problem-solving behaviors were videotaped. During that process, the researcher asked questions about why the students were doing certain things and offered help intended to cue particular cognitive behaviors. The researcher also kept a record of the commands students used to solve the problems, believing these represented their manipulation of the materials, the "concrete ideas/abstract objects" of Logo programming.

Subjects

The study was conducted with 11 fourth- and fifth-grade students at a private elementary school in Brattleboro, Vermont. Participating students included 1 fourth-grade and 4 fifth-grade girls, and 4 fourth-grade and 2 fifth-grade boys. All students came from rural, middle-class families. They ranged in age from 8.75 to 11.5 years, and in ability from learning-disabled to academically gifted. All were beginning Logo programmers. They had been meeting once a week with the author for approximately 10 weeks at the time the study was conducted, and used the LCSI *LogoWriter* version of the language on Apple IIe computers.

Procedures

Each student was given three graphic designs drawn on cardboard and asked to reproduce them on the computer (Figure 1). The first was a square with a triangle on its right edge, the second was a square in the upper right corner of the computer screen, and the third was a border drawn around the screen. The three designs were chosen because they were relatively simple but could be broken into two or more distinct parts in terms of their solutions and because those solutions could be related one to another.

The students were simply asked to reproduce the designs. They were given no constraints concerning how they should draw them, other than that they should use Logo and that the result should appear on the computer screen. Interestingly, although all the students had experience writing Logo procedures, all but one used Logo's immediate mode to solve the problems, and that student merely used procedures he had already created. As the students solved each of the problems, they were asked to tell what they were thinking. They were also asked for explanations of certain behaviors, and they were provided with support when they needed it. Each student's work on all three problems was videotaped, and their conversations with the researcher were transcribed. In addition, all the programming commands used in each solution were recorded. The transcriptions and the command records were then integrated to produce the problem-solving protocols used as data in the study.

Analyses

As any programming teacher knows, there is never a single correct way to solve a programming problem. Not surprisingly, then, the integrated protocols show that none of the students solved any of these seemingly simple problems in exactly the same way. In analyzing the protocols, however, certain dimensions emerged along which student behaviors could be distinguished. These fell into three categories: domain knowledge, cognitive styles, and problem-solving strategies. The following sections explore each of these categories, distinguish dimensions within them, and define variations within these dimensions.

Domain Knowledge

"Domain knowledge" refers to knowledge and skills specific to a particular discipline or cognitive aptitude. Everyone brings a unique combinations of domain knowledge to problem-solving tasks. To a greater or lesser extent, these differences can reasonably be assumed to affect the ways in which those tasks are negotiated. In the current study, three sorts of domain knowledge were deemed relevant to the tasks at hand: students' knowledge of Logo programming, their mathematical understanding, and their

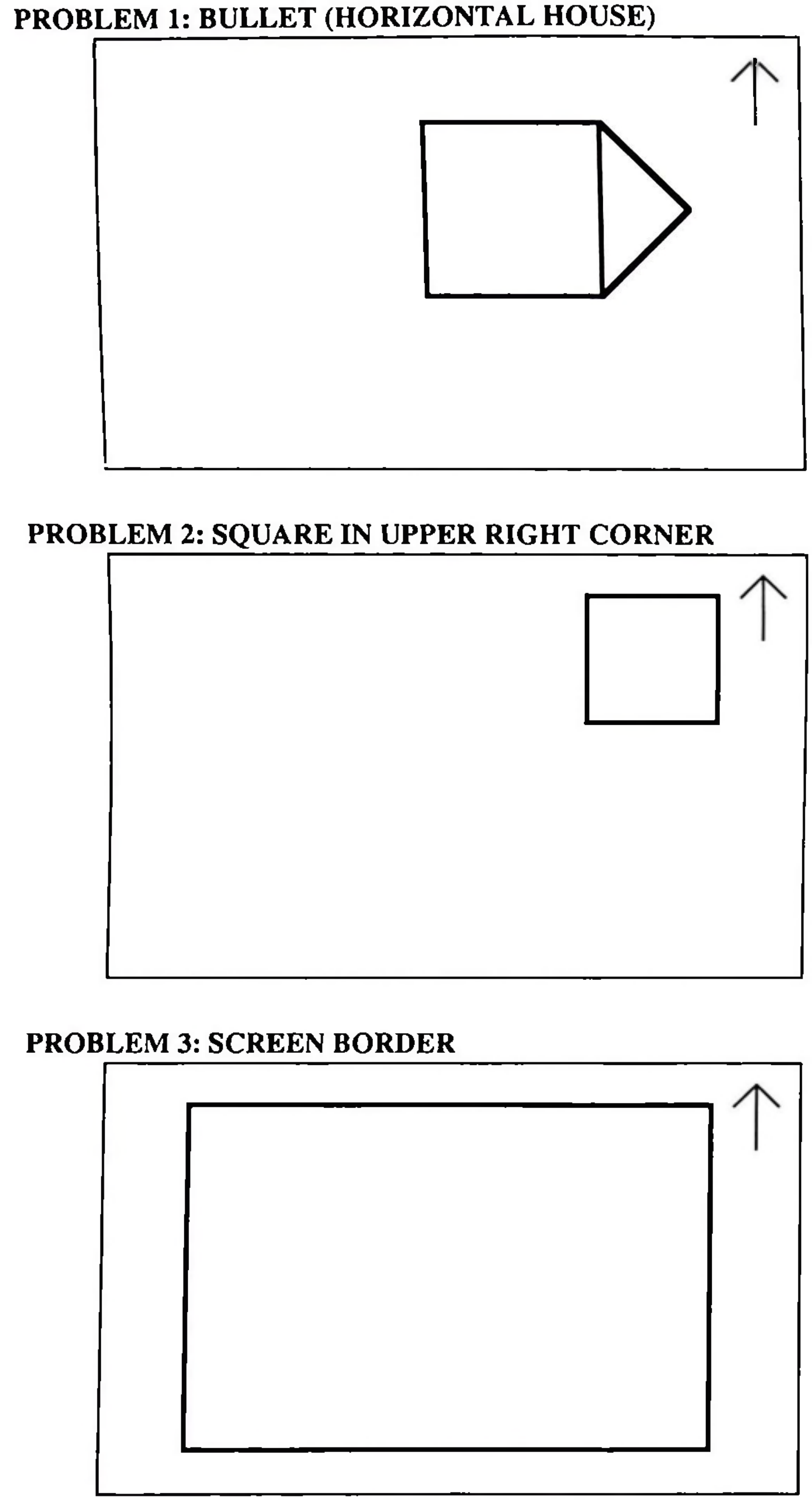

Figure 1. Logo Programming Problems

spatial intelligence (Gardner, 1983). Each of these is outlined in Table 1 and discussed in more detail in the sections that follow.

Table 1
Domain Knowledge Distinctions

Logo Programming	
very good (**VG**)	student shows ready grasp of basic Logo graphics commands; student uses more advanced Logo commands; student exhibits a good sense of units of distance and degrees of turns in Logo; student uses square formula
average (**OK**)	student demonstrates knowledge of basic Logo graphics commands; student shows some sense of units of distance and degrees of turns
not good (**NG**)	student isn't sure of basic Logo graphics commands; student does not show any sense of units of distance or degrees of turns
Mathematical Understanding	
very good (**VG**)	student mentally manipulates quantities; student demonstrates mathematical thinking
average (**OK**)	student shows no evidence of mathematical thinking; student minimally manipulates quantities (one or two examples of quantities involving only numbers in multiples of ten and less than 100)
not good (**NG**)	student shows no evidence of mathematical thinking; student shows difficulty in mentally manipulating numbers
Spatial Intelligence	
good to average (**OK**)	no evidence of difficulty in discriminating left from right
not good (**NG**)	evidence of difficulty in discriminating left from right

Logo Programming. Just as reading entails more than simply decoding written language, so the knowledge of Logo programming entails more than simply knowing the meanings of its commands. Considering that they were all novice programmers, the students involved in the study exhibited a surprising range of understanding of basic Logo commands. While the majority of students demonstrated that they knew basic graphics commands (i.e., FD, BK, RT, LT, PU, PD), three students were very shaky with even these. At the other extreme, one student easily used the more advanced SETH ("set heading") command. Some students showed they had a good sense of units of distance and degrees of turns; others showed they didn't. Some students understood the reversibility of FD and BK, RT and LT; others didn't. Finally, although several students seemed to have a relatively automated idea of how to make a square, the majority had to work the whole figure out.

For the purposes of this study, three levels of Logo programming knowledge were distinguished (see Table 1). Students who exhibited a ready grasp of Logo graphics commands including a good sense of distances and degrees of turns, who used more advanced Logo commands, and/or who showed that they knew the formula for a square were categorized as "very good" (**VG**) programmers. Students who exhibited a working knowledge of basic Logo graphics commands and some sense of distances and turns where categorized as "average" (**OK**) programmers. Students who had difficulty with basic Logo graphics commands and/or distances and turns were categorized as "not good" (**NG**) programmers.

Mathematics. The students in the study also exhibited a range of mathematical nowledge and skills. Many students were obviously able to mentally combine and/or plit apart quantities, but some could only combine certain quantities, and at least one had trouble combining even simple quantities.

For the purposes of this study, three levels of mathematical knowledge were distinguished (see Table 1). Students who exhibited the ability to mentally manipulate quantities, including quantities over 100, and who exhibited mathematical thinking were categorized as having "very good" (**VG**) mathematical abilities. Students who minimally manipulated quantities mentally, but never numbers greater than 100, and who exhibited no mathematical thinking were categorized as having "average" (**OK**) mathematical abilities. Students who exhibited difficulty in manipulating simple quantities mentally and gave no evidence of mathematical thinking were categorized as "not good" (**NG**) in mathematical abilities.

Spatial Discrimination/Directionality. Two students in the study seemed yet to have mastered directionality—they had a difficult time distinguishing between left and right. In one case, this made figuring turns especially laborious. The other student, Kathy, is the student who had mastered the SETH command. Indeed, Kathy had probably the most complete domain knowledge of Logo programming of any of the students involved in the study. She stated that she used SETH for all her turns (except the ones embedded in the square, which she had automated) precisely because she had a hard time distinguishing left from right. Kathy's use of SETH is a good example of the use of ability in one domain to compensate for a lack of knowledge or skill in another.

For the purposes of this study, students' knowledge of directionality was simply categorized according to whether they could (**OK**) or could not (**NG**) readily distinguish left and right (see Table 1).

Cognitive Styles

In their recent article on styles and voices within the computer culture, Turkle and Papert (1990) used the term "styles" to refer to different approaches to knowledge in the Piagetian model. They argued, however, that such cognitive styles do not represent stages in the evolution of formal reason (Piaget, 1971) but rather that each is equally valid on its own terms. Whether or not cognitive styles represent developmental stages or mature diversity, they could affect the ways in which problems are solved. This article employs the term "cognitive styles" in this manner, and it is in this sense that several distinct cognitive styles (as compared with the single dichotomy described by Turkle and Papert) emerged from analyzing the integrated protocols. These can be categorized in terms of the following dichotomies: global versus local problem representation, abstract versus concrete thinking, and top-down versus bottom-up planning. Each of these is outlined in Table 2 and described in more detail in the following sections.

Table 2
Cognitive Style Distinctions

Problem Representation	
global (**GL**)	evidence that student considers specific parts of the problem in relationship to other parts
local (**LO**)	no evidence that student considers specific parts of the problem in relationship to other parts, other than in the relationship of one command to preceding commands
Thought	
abstract (**ABS**)	evidence of systematic testing, use of formulas for shapes, mental calculations; abstract use of reversibility
concrete (**CON**)	no evidence of systematic testing, use of formulas, or mental calculations; student anchors reversibility in concrete experience; student uses idiosyncratic numbers
Planning	
top-down (**TD**)	evidence of planning based on consideration of the problem as whole
bottom-up (**BU**)	no evidence of planning based on whole problem; student discovers problem solution through the problem-solving experience

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top-down (**TD**)	evidence of planning based on consideration of the problem as whole
bottom-up (**BU**)	no evidence of planning based on whole problem; student discovers problem solution through the problem-solving experience

Global Versus Local Problem Representation. The distinction between global and local problem representation is found in whether or not students consider specific parts of a problem in relation to others (see Table 2). The problem representations of students, for example, who considered the parts of the triangle and the square in Problem 1 (see Figure 1) in relationship to each other, or who used a formula to describe the various squares, were categorized as "global" (**GL**). April's solution to the third problem, for example, contains many good examples of global thinking:

(In this and in all examples given in this article, Logo commands are shown in plain type, student comments are shown in italics, the researcher's (real time) comments are in italics inside angled brackets (<>), and researcher's later explanations are given in plain text inside parentheses. Students' names have been changed to ensure confidentiality.)

... LT 90
FD 130 – (this sends the turtle right to the lower left corner)
<Oh wow, how'd you know 130?>
I don't know, I guessed.
RT 90 – (she takes the turns for granted)
FD 130
Cause that's about the length of that – (she compares the line she has already drawn half way across the bottom of the screen with the distance she needs to cover up the left side of the screen) – *Oops, not quite enough*
FD 20
All right.
RT 90
Now I'm going to go forward um ... OK so now I'm going to go ... Let's see, it was 150 to there – (she examines the line she has drawn on the left side of the screen, then notices the line she has drawn half way across the bottom and chooses that as her measure.) – *Let's see, it was ... well, it was 130 to there* – (points half way across the top of the screen comparing it to the bottom) – *so that's probably ... 260, I guess ... All right*
FD 260
... (APRIL, PROBLEM 3)

On the other hand, the problem representations of students who considered each command sequence in itself or in relation to the commands immediately preceding it were categorized as "local" (**LOC**). An extreme example of a local problem representation accounts for Laura's divergence from the given drawing to relate what she was doing to what she had already drawn:

... *So I have to make a square ...*
– (Laura doesn't seem to see that the square is in the upper right corner; she just makes a square. In the previous problem, she similarly didn't include the line splitting the triangle and the square.)
FD, hmmm...
FD 40
... (LAURA, PROBLEM 2)

Abstract Versus Concrete Thought. Piaget (1971) made the classic distinction between formal mental manipulation and thinking that is grounded in concrete objects (see Table 2). In this study, planning ahead, systematic testing, use of formulas, and mentally combining or splitting apart quantities to calculate distances or turns were all considered evidence of "abstract" (**ABS**) thought. The lack of these, together with the use of idiosyncratic numbers, was considered evidence of "concrete" (**CON**) thought. In addition, a distinction was made between abstract and concrete uses of reversibility.

Reversibility has to do with the fact that in Logo the left (LT) command is the opposite of the right (RT) command and the back (BK) command is the opposite of the forward (FD) command. When students turned the turtle in the wrong direction or moved it too far, they could correct their errors by making use of this concept. Some students simply turned or moved the turtle the distance they had gone in the wrong direction plus the distance they wanted to go in the first place. These students were categorized as abstract (**ABS**) thinkers. Other students seemed to need to get the turtle back to where they went wrong, to anchor their thinking in a concrete experience, before they turned or moved in the correct direction. These students' thought was categorized as concrete (**CON**).

For example, in working on the second problem (see Figure 1), April exhibited abstract thinking when she kept going with the square she was drawing, even though she forgot to put the pen down:

```
... FD 40
Oops, I forgot to put the pen down.
PD
RT 90
FD 40
RT 90
FD 40
RT 90
FD 40
RT 90
FD 40
Ididit.
HT (APRIL, PROBLEM 2)
```

In contrast, when Lilly made a similar mistake in the second problem, she went back and put the pen down before drawing the square. When she turned the wrong way, she first turned back to where she started and then made the correct turn. Lilly's thinking was therefore categorized as concrete.

```
... FD 30
Oh, I keep on forgetting to put the pen down.
BK 30
PD
FD 30
There!
—(plays turtle)
```

RT 90
— (Lilly shakes her head because the turtle has again turned the wrong way.)
LT 90
LT 90
FD 30
... (LILLY, PROBLEM 2)

Top-Down Versus Bottom-Up Planning. The distinction between behaviors categorized as top-down (**TD**) or bottom-up (**BU**) planning involved whether students approached a problem as if it consisted of distinct smaller problems, or whether they approached that problem as a single command sequence to be discovered one step at a time (see Table 2). Students such as Tom, who used a top-down approach, planned what they were going to do before doing it:

... Yeah. See I'm going to be going FD 30 all around this thing and then I'm going to go RT 90 to make the turns, so that will be easy, but then when I get to the triangle, I'm going to have to figure out a bunch of different stuff.
... (TOM, PROBLEM 1)

On the other hand, students who used a bottom-up approach "discovered" their plan from the problem-solving experience itself. Lilly, for example, considered each piece of her solution as it unfolded in the programming sequence rather than in relationship to a larger, preplanned design:

... <What are you thinking about?>
How far up the line should be.
<Oh, OK, the first line that you're drawing?>
Yeah.
... <Now what are you thinking about?>
Which way I should turn the turtle to make him go down.
... <OK, now what are you going to do?>
I'm going to put the pen down, go up to the top, actually go up on this side.
... (LILLY, PROBLEM 1)

Problem-Solving Strategies

A number of distinct problem-solving strategies can be distinguished within general problem-solving behaviors (Newell & Simon, 1972; Wicklegren, 1974). Certain of these seem more applicable to programming problems in general and to children's programming in particular (Clements & Gullo, 1984; Lawler, 1985). In previous work (Swan & Black, 1989), five such problem-solving strategies that seemed well-represented in Logo programming environments — forward chaining, analogy, alternative representation, subgoals formation, and systematic trial and error—were isolated. These strategy distinctions, as explained in Table 3 and in the following sections, were carried over to the current study.

Forward Chaining. Forward chaining is a species of means-ends analysis (Newell & Simon, 1972) that involves working from what is given in a problem toward the

Table 3
Problem-Solving Strategies

forward chaining **(F. CHAIN)**	quantities to get progressively closer to the drawing of a single line or angle
analogy **(ANALOGY)**	evidence that student has used solution to one problem to help solve another
alternative representation **(ALT. REP.)**	evidence that student has reconceptualized a problem to solve it
subgoals formation **(SUBGOALS)**	student breaks the problem into distinct, chunked parts
systematic trial & error **(SYST. T&E)**	student systematically tests quantities needed for distances or turns by picking the pen up and trying them

problem goal in step-by-step, transformational increments. Of course, most programming activity involves some forward chaining. In the current study, programming behaviors were categorized as utilizing forward chaining (**F. CHAIN**) strategies only when students used forward chaining in the extreme; that is, only when they used repetitions of known quantities to move the turtle a single distance or turn, i.e.:

```
... PU
FD 100 – X 2 – (using the arrow and return keys)
<So you're moving it forward first, ...>
Whoooh, it wrapped around the screen.
FD 10 – X 5 – (using the arrow and return keys)
<Why did you go back over your old stuff?>
Well, I was trying to figure out, I was trying to... I messed myself up, I shouldn't
have ... I was trying to change the LT to something else.
<Oh.>
RT 90
FD 20 – X 2 – (using the arrow and return keys)
LT 90
<Now why are you turning left?>
So I can go up a little bit.
<Go up for what?>
To get it a little bit up more on the screen.
<Oh.>
FD 5 – X 2 (using the arrow and return keys)
RT 90
<Now why are you turning it right?>
So I can move it over here.
FD 5 – X 5 – (using the arrow and return keys)
RT 90
```

<Now you turned it right again. What did you do that for?>
So I can start making my square.
– (TOM, PROBLEM 2)

Analogy. Analogy involves the discovery of a particular similarity between two problems and "a mapping of knowledge from one (the base) onto another (the target), predicated on a system of relations that holds among the objects of both domains" (Gentner, 1987). In the current study, students were categorized as using analogy (**ANALOGY**) strategies when they used techniques from one problem to solve a part of another problem. Kathy, for example, used an enlarged square procedure to draw the border for Problem 3 (see Figure 1). In the following protocol, notice also her use of systematic trial and error and abstract reasoning:

```
– I'm going to go to one of the corners and make a square with, instead of 40, like
100 or something.
SETH 135
PU
FD 85
FD 12
SETH 0
REPEAT 1[FD 100]
<What's the matter?>
I was just seeing if I might just want to do it once to see if it will work.
<Without the pen down?>
Yeah.
<Oh, I see what you're doing. That was a good idea.>
– (started with a regular square then amended to this as she realized that 100 steps
for each side might not be enough)
FD 60
To get the turtle to the edge of the screen.
BK 10
<Now what are you doing?>
I'm going to go back 150 and ...
BK 150 – (did figuring in her head here: 100 + 60 - 10)
<How'd you know 150?>
Because I did FD 100 and it was about here, so I did FD 60 and it went too far, so
I did back 10.
<So you added and subtracted.>
Yes.
REPEAT 4[FD 150 LT 90] – (changes RT to LT in square formula)
Whoops.
PD
REPEAT 4[FD 150 LT 90]
HT
(KATHY, PROBLEM 3)
```

Alternative Representation. Alternative representation involves reconceptualizing a problem from differing perspectives. In the current study, students were judged as using alternative representation (**ALT. REP.**) strategies when there was clear evidence of reconceptualization. Interestingly, in all such cases reconceptualization took place as a result of the lack of the specific domain knowledge necessary to solve a particular problem. Robert, for example, made use of the square procedure he had saved to disk when he encountered difficulty making a square from scratch:

... Can I write "square"?
<What happens if you write "square"?>
Then I'll have a square.
<OK, do that.>
No.
<What's the problem?>
I didn't have a square in there.
<You didn't make a program that draws a square, right?>
No.
<Do you know how to write one? Do you know how to make a program that draws a square?>
Uh uh. – (no)
<Well, then, I guess you can't do that. Let's do something else. What do you know how to do?>
Well, is this my program?
<No, do you want your program?>
Yes, 'cause that will be easier.
– (gets his disk, loads it, goes to the page with shapes on it, checks flipside for name of procedure)
Oh, SQ is it.
SQ
... (ROBERT, PROBLEM 1)

Subgoals Formation. Subgoals formation refers to breaking a single difficult problem into two or more simpler problems. In the current study, students showed subgoals formation (**SUBGOALS**) when they explicitly stated that they were breaking problems into distinct parts, i.e.:

... <So what are you going to do?>
Well, I already know the direction so I can start over again.
RG
OK, now I'm going to make the square and then make the triangle.
... (DOUG, PROBLEM 1)

Systematic Trial and Error. Systematic trial and error involves the testing of possible solutions in a systematic, guided fashion. This differs from forward chaining in that it includes negative inference (problem-reduction through the elimination of possibilities) as well as positive inference, and in that its power lies in the systematic testing of such possibilities rather than in the immediate choice of the best one. As with forward chaining, almost all programming involves some use of systematic trial-and-error strategies. In the current study, therefore, only when students picked the pen up and tested a move before implementing it was their behavior categorized as involving systematic trial-and-error (**SYST. T&E**) strategies, i.e.:

```
… <Now what are you thinking?>
I'm trying to figure out how much to turn – (plays turtle) – OK.
RT 70 – (draws on screen with his finger)
PU
FD 10
BK 10 – (tests it)
LT 40
<Why are you using LT now?>
To turn it back.
<Oh, good.>
FD 10
See if that's right, I'm not sure.
BK 10
Yup.
PD
… (SAM, PROBLEM 1)
```

Because explicit operational definitions were developed for each of the preceding problem-solving strategies, one or more students could possibly not have demonstrated the use of any of these strategies. This, however, was not the case. All the students who participated in the study used at least one of the identified strategies. This finding seems to indicate that people naturally employ some strategy when faced with problems to solve. The question then becomes: When and why do they use differing problem-solving strategies? The following section explores this question by exploring patterns of strategy choice among the students.

Results

Figure 2 summarizes the results of the analyses of the integrated protocols. It shows the gender and grade as well as the domain knowledge, cognitive styles, and problem-solving strategies employed by each participating student. Although the study is clearly preliminary, several interesting patterns relating domain knowledge, cognitive styles, and problem-solving strategies emerged. These are discussed in the sections that follow.

Because of their importance to developmental (Piaget, 1971) and cognitive-style (Turkle & Papert, 1990) explanations in problem-solving behaviors, gender and grade-level distinctions are discussed in the first section. The second and third sections that follow discuss relationships between domain knowledge and problem-solving on the one hand and between cognitive styles and problem-solving on the other.

Gender and Grade

In their discussion of cognitive styles, Turkle and Papert (1990) relate top-down and bottom-up approaches in programming to males and females, respectively. The results of this study confirm their observations, at least with respect to males. Five of the six boys participating in the study were identified as using top-down planning, as compared to three of the five participating girls. Girls seemed more inclined than boys to represent problems globally (3 girls, 1 boy), and, conversely, boys seemed more inclined than girls

		APRIL	BIANCA	DOUG	JASON	KATHY	LAURA	LILLY	ROBERT	TOM	SAM	SETH
	GENDER	F	F	M	M	F	F	F	M	M	M	M
	GRADE	5	4	4	4	5	5	5	4	5	4	5
DOMAIN K.	LOGO	VG	OK	NG	OK	VG	OK	OK	NG	OK	OK	NG
	MATH	VG	VG	VG	OK	VG	NG	OK	OK	OK	VG	NG
	DIRECTION.	OK	OK	OK	OK	NG	OK	NG	OK	OK	OK	OK
COG. STYLES	PROB. REP.	GL	GL	LOC	LOC	GL	LOC	LOC	LOC	LOC	GL	LOC
	THOUGHT	ABS	ABS	ABS	ABS	ABS	CON	CON	CON	ABS	ABS	CON
	PLANNING	TD	TD	TD	TD	TD	BU	BU	TD	TD	TD	BU
PROB. SOL. STRATS.	F. CHAIN.				YES		YES	YES	YES	YES		YES
	ANALOGY					YES			YES			
	ALT. REP.					YES			YES	YES		
	SUBGOALS	YES	YES	YES	YES	YES				YES		
	SYST. T&E					YES					YES	

Figure 2. Domain Knowledge, Cognitive Styles, and Problem-Solving Strategies

to represent them locally (5 boys, 2 girls). These results lend support to Turkle and Papert's argument that programming instruction that forces students to use particular cognitive styles may be gender biased. As such, these issues clearly deserve further investigation. No other gender differences in cognitive styles were noted.

Grade-level distinctions in cognitive styles were minimal and, at that, ran counter to what might be expected from a developmental perspective (Ginsburg & Opper, 1980). More fifth graders (3) than fourth graders (1) were categorized as concrete thinkers, and all the students characterized as bottom-up planners (3) were fifth graders. Such findings tend to support Turkle and Papert's contention that cognitive styles do not represent stages in the evolution of formal reason but rather that each is equally valid on its own terms. No other grade-level distinctions in cognitive styles were noted.

Few gender or grade-level distinctions were found in the problem-solving strategies the students employed. Boys were more likely than girls to use extreme forward chaining strategies (4 boys, 2 girls), a preference probably related to their propensity for local problem representation, as were fifth-graders (4 fifth, 2 fourth). No ready explanation for this latter finding comes to mind. The two students who used systematic trial-and-error strategies were both fifth graders, which taken by itself might be seen as supporting developmental explanations (Ginsburg & Opper, 1980). No other gender or grade-level distinctions were noted in the problem-solving strategies utilized by these students.

Domain Knowledge

There has been a long-standing controversy between cognitive psychologists who believe that problem-solving is always domain specific (Griggs, 1989; Johnson-Laird, Legrenzi & Legrenzi, 1972; Reich & Ruth, 1982) and those who believe that general problem-solving strategies are applied across domains (Anderson, 1984; Braine, Reiser, & Rumain, 1984; Geis & Zwicky, 1971; Henle, 1962). Developmentalists (Ginsburg & Opper, 1980; Piaget, 1971) strongly favor the latter view and relate the development of problem-solving abilities to their natural emergence with maturity. Although this author also subscribes to the latter position, it is clear that one's knowledge of a particular domain will significantly affect the ways in which he or she attempts to solve problems therein. This section accordingly examines results concerning the relationships between domain knowledge and the cognitive styles and problem-solving strategies employed by the students.

Figure 3 shows relationships between students' Logo programming skills and their mathematical abilities. The rows distinguish between "very good," "average," and "not good" Logo programming proficiency; the columns distinguish between "very good," "average," and "not good" mathematical skills. The numbers in the cells indicate the numbers of students who were judged to have the particular combination of domain knowledge designated by the rows and columns defining them. Figure 3 shows that although there seems to have been a general tendency for those who were good in one area to be good in the other, and vice versa, there was not necessarily a connection between the skills. In particular, students who were categorized as having "very good" mathematical skills exhibited a full range of Logo programming skills.

No relationships emerged between spatial discrimination skills and either Logo programming or mathematical abilities. Indeed, of the two students categorized as exhibiting poor spatial discrimination, one was also categorized as having very good mathematical and Logo programming skills, while the other was categorized as having only average skills in these areas. All other students who demonstrated a full range of mathematical and programming abilities were found to have adequate spatial discrimination skills.

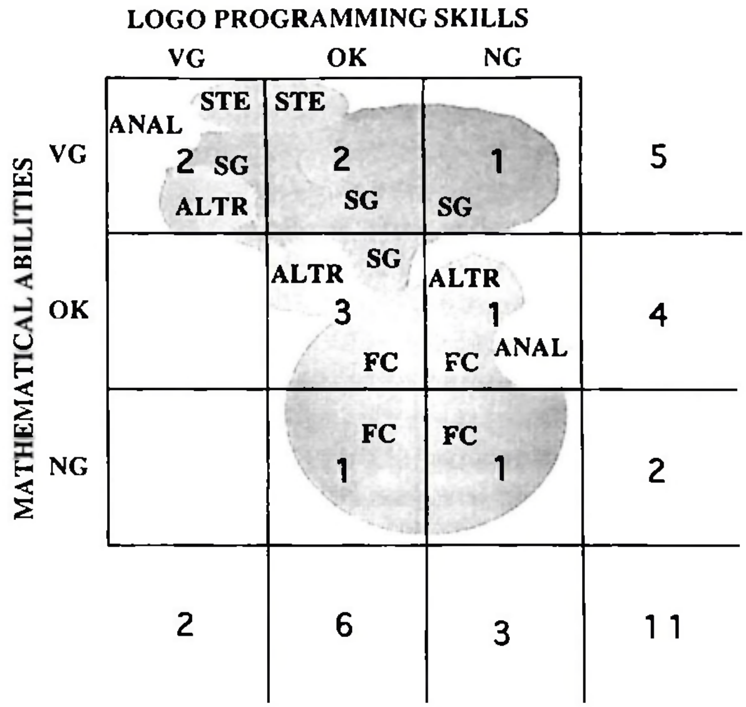

Figure 3. Relationships Between Domain Knowledge and Problem-Solving Strategies

The problem-solving strategies employed to solve the Logo programming problems, however, did seem to be related to domain knowledge. Figure 4 superimposes such strategies over the domain knowledge grid shown in Figure 3 by associating the use of particular strategies with the domain knowledge combinations of students exhibiting such usage. In this representation, some interesting patterns emerge. For example, students with poor mathematical abilities used extreme forward-chaining strategies exclusively, while students with "very good" mathematical skills did not use them at all. Systematic trial-and-error strategies were used only by students with "very good" mathematical skills and "very good" to "average" Logo programming abilities. Subgoals formation strategies were used only by students with "very good" to "average" mathematical knowledge. Finally, analogy and alternative representation strategies were used by students with a broad range of domain knowledge combinations.

Although the domain knowledge grid in Figure 4 does not show spatial discrimination, a very interesting relationship between poor spatial discrimination and the other knowledge domains may have affected the problem-solving strategies employed by at least one student. As previously noted, two students exhibited poor spatial discrimination skills. One of these students, Kathy, was characterized as having "very good" mathematical and Logo programming knowledge. Spatial discrimination problems seem not to have affected her choice of problem-solving strategies. The other student, Lilly, was characterized as having "average" mathematical and Logo programming knowledge. In Lilly's case, spatial discrimination problems did seem to affect her choice

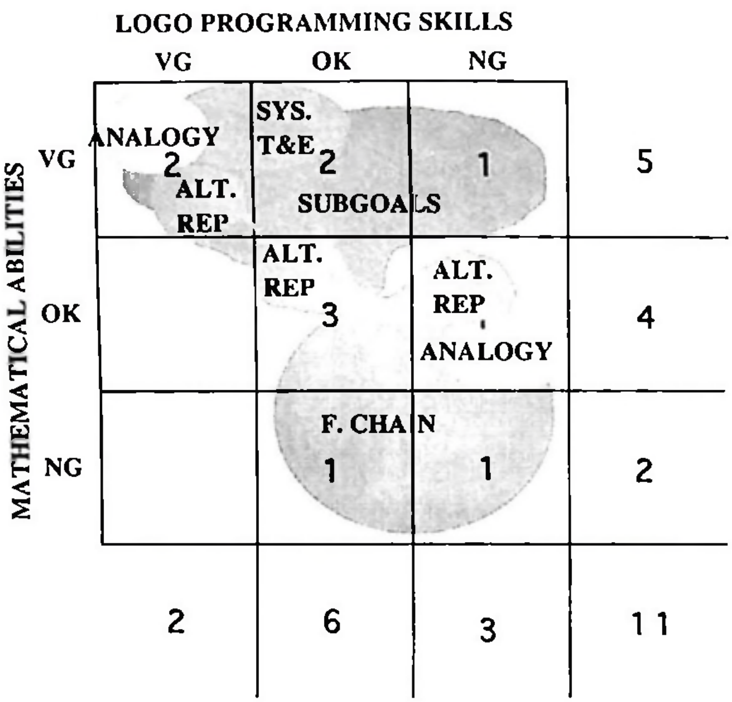

Figure 4. Relationships Between Domain Knowledge and Problem-Solving Strategies (Superimposed Strategies)

of problem-solving strategies. Lilly used extreme forward-chaining strategies exclusively, while the other two students characterized as having "average" mathematical and Logo programming knowledge used extreme forward chaining in combination with subgoals formation.

There is another very compelling relationship between domain knowledge and problem-solving strategies employed. All three students who used alternative representation strategies seemed to do so in response to a particular lack of specific domain knowledge. We have already seen how Robert used a previously written square program when he realized he had forgotten how to make a square. Tom drew a line he didn't want, but he didn't know the pen erase (PE) command. He turned the pen color to black (the background color) and simply drew over the line. Kathy was aware of her difficulty in distinguishing left from right and therefore used set heading (SETH) as an alternative to right (RT) and left (LT) for turning the turtle:

```
... <What are you thinking now?>
I need to get the pen up and then move it so my turtle is right here.
<OK.>
PU
SETH 45
<You used set heading.>
Yes
<That's clever.>
```

```
I always get mixed up with which way right is and which way left is.
… (KATHY, PROBLEM 2)
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These examples support the notion that use of alternative representation strategies can be triggered when a problem solution is blocked by a lack of domain knowledge (Duncker, 1945).

Figure 5 superimposes cognitive styles over the domain knowledge grid shown in Figure 3. The patterned areas in Figure 5 delineate combinations of cognitive styles. For example, the diagonally-striped area in the upper left corner represents students who exhibited global problem representation, abstract thinking, and top-down planning. Figure 5 shows that those students were also categorized as having "very good" mathematical skills and "very good" to "average" knowledge of Logo programming. The lines splitting the grid show the boundaries between cognitive style dichotomies—global versus local problem representation, abstract versus concrete thinking, top-down versus bottom-up planning. These tell us, for example, that all the students who demonstrated top-down planning were also categorized as having "average" to "very good" mathematical knowledge.

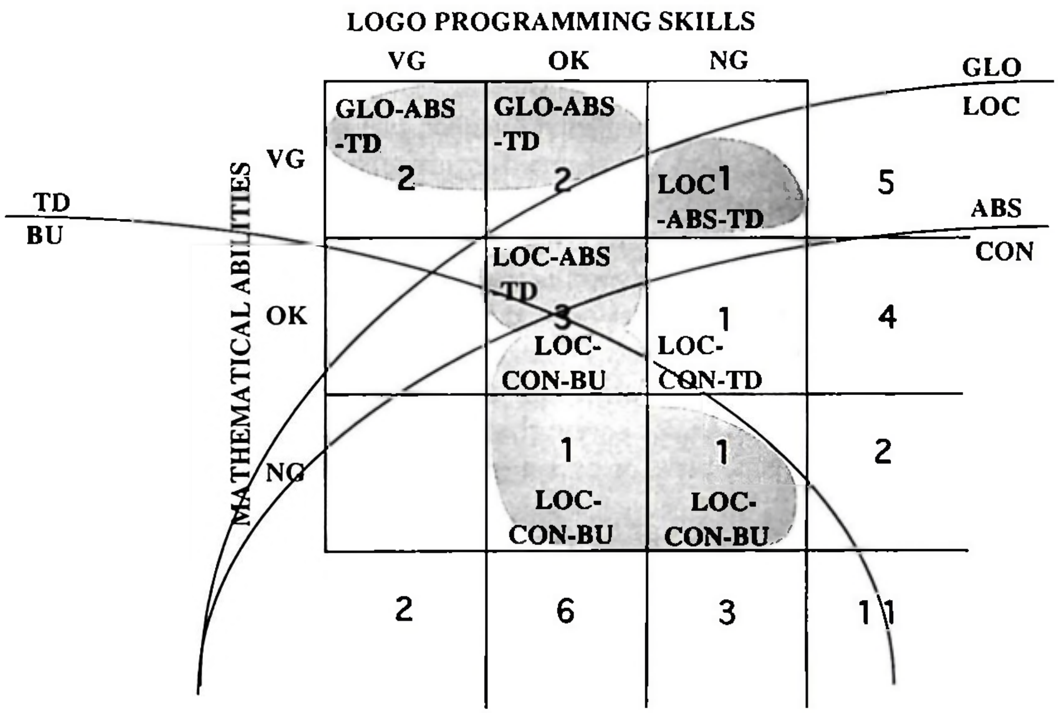

Figure 5. Relationships Between Domain Knowledge and Cognitive Styles

The patterns that emerge in Figure 5 are very similar to those shown in Figure 4. They tell us that in addition to the relationship between top-down planning and "average" to "very good" mathematical ability previously noted, all the students who were categorized as abstract thinkers were also categorized as having "average" to "very good" mathematical abilities. All the students who represented problems globally were judged to have "very good" mathematical skills, while all the students who were categorized as concrete thinkers had "average" to "not good" mathematical skills. However, Figure 5 does not show that the division between students who exhibited local problem representation, abstract thinking, and top-down planning and the student who demonstrated local problem representation, concrete thinking, and bottom-up planning found in the center square of the grid ("average" domain knowledge on both dimensions) is most likely related to that student's spatial discrimination problems.

Thus, we can see a general tendency for better domain knowledge combinations to be related to particular cognitive styles (i.e., global problem representation, abstract thinking, and top-down planning) and vice versa (i.e., bottom-up planning and concrete thinking) and for better domain knowledge combinations to be related to the use of specific problem-solving strategies (i.e., systematic trial and error and subgoals formation) and vice versa (i.e., forward chaining). Such findings suggest that something more than either development (Piaget, 1971) or disposition (Turkle & Papert, 1990) was at work here. What is most interesting, however, is how similar those tendencies are. This finding is discussed in the following section.

Cognitive Styles

When Figures 4 and 5 are considered together, one is struck by the fact that the patterns of problem-solving strategy usage and cognitive style are nearly identical. These relationships are detailed in Figure 6, which gives the problem-solving strategies used by students with varying cognitive styles. The three lines indicate the global versus local problem representation, abstract versus concrete thinking, and top-down versus bottom-up planning distinctions. The angles created by those lines thus enclose the various possible cognitive style combinations. For example, the bottom right corner of Figure 6 encloses the local problem representation, concrete thinking, bottom-up planning combination. Notice that no students were characterized as both representing problems globally and thinking concretely or as being bottom-up planners and using global representations.

Figure 6 tells us that only the students who represented problems globally also employed systematic trial-and-error strategies; that only the students who represented problems locally also used extreme forward-chaining strategies; that only abstract thinkers also used subgoals formation strategies; that only top-down planners also used analogy and alternative representation strategies; and that only bottom-up planners also used extreme forward-chaining strategies exclusively. We can conclude, then, that cognitive style combinations were more closely related to problem-solving strategies than were domain knowledge combinations. Such finding would tend to support arguments for the existence of general problem-solving skills that are applied across domains (Anderson, 1984).

Figure 7 represents the relationships between cognitive styles and problem-solving strategies found among students participating in the study. In this representation, the

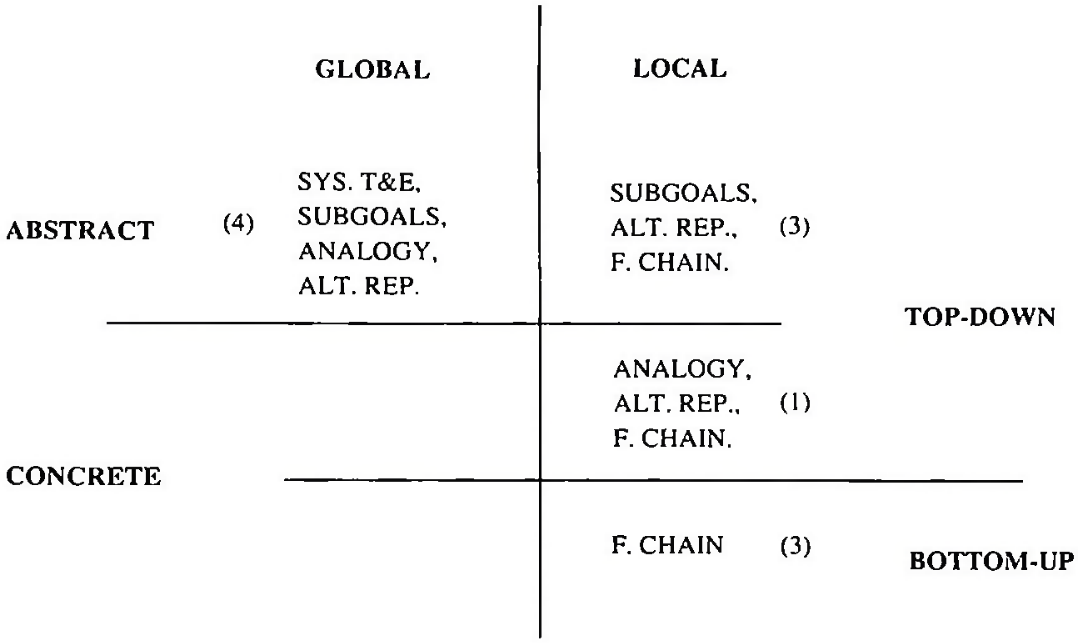

Figure 6. Problem-Solving Strategies Used by Students With Varying Cognitive Styles

ellipses designate the various cognitive style distinctions—the thin solid lines enclose areas representing the global/local problem representation distinction, the striped lines enclose areas representing the abstract/concrete thinking distinction, and the thick solid lines enclose areas representing the top-down/bottom-up planning distinction. The numbers in parentheses indicate the number of students who exhibited each particular cognitive style. The numbers not in parentheses indicate the number of students who exhibited particular cognitive style combinations, namely, those combinations indicated by the overlapping ellipses in which they are found.

Figure 7 also relates particular problem-solving strategies to the cognitive styles with which they were exclusively associated. Analogy and alternative representation strategies are linked to top-down planning because only students who were categorized as top-down planners employed those strategies. Extreme forward-chaining strategies are linked to local problem representation because only students categorized as representing problems locally used extreme forward-chaining strategies. Global problem representation and systematic trial-and-error strategies and abstract thinking and subgoals formation strategies were found to be similarly linked.

Several quite interesting observations can be made based on the diagram in Figure 7. As previously noted, particular problem-solving strategies were linked with specific cognitive styles. This suggests that the concept of "cognitive style" might be quite instructionally important. Individualizing problem-solving instruction might be useful, for example, by focusing on the development of particular problem-solving strategies

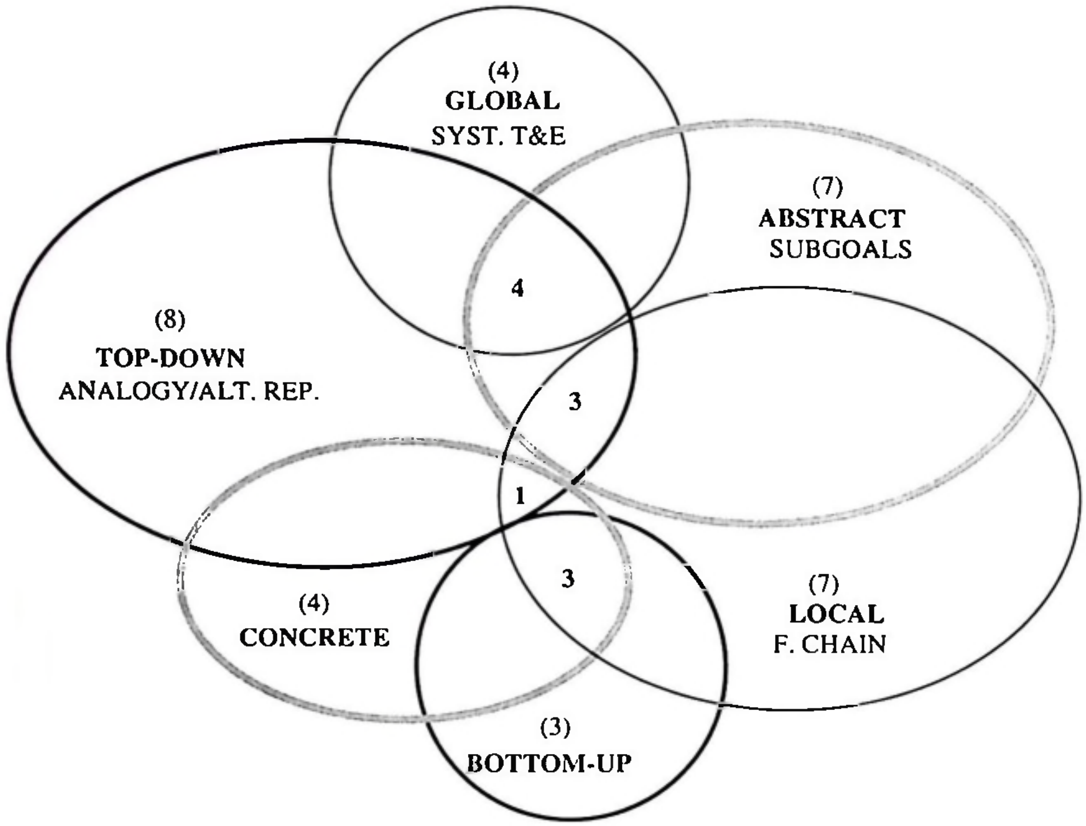

Figure 7. Relationships Among Cognitive Styles and Problem-Solving Strategies

appropriate to individual students' specific cognitive styles. Conversely, trying to develop problem-solving strategies might be useless, if not harmful, to students whose cognitive styles are not suited to them. This seems to be in part what Turkle and Papert (1990) suggest.

Second, although certain cognitive style/problem-solving strategy associations seem relatively obvious, others do not. The linking of local problem representation with extreme forward-chaining strategies, for example, makes a certain kind of sense, in that it seems logical that only students who represented problems locally would use a problem-solving strategy so locally grounded. Likewise, it makes sense that only students who consider a problem as a whole (top-down planning) could relate that problem to previous problems (analogy) or alternatively represent it. On the other hand, systematic trial-and-error strategies seem more logically related to abstract thinking than to global problem representation. Indeed, the use of systematic trial-and-error strategies is one of the criteria Piaget (1971) gives for abstract thought. Similarly, subgoals formation strategies seem more logically related to top-down planning.

Third, all of the cognitive style distinctions shown in Figure 7 overlap. Thus, although most of the students who were categorized as top-down planners were also categorized as abstract thinkers, one was not. This indicates that the distinctions do not refer to identical behaviors, suggesting that cognitive styles cannot be unilaterally described. In particular, the distinctions between concrete and abstract thought made by Piaget (1971) and between top-down and bottom-up planning made by Turkle and Papert (1990) may describe different dimensions of cognition and should, therefore, be considered as such. To these unique cognitive style dimensions, the current study adds a third, that of global/local problem representation.

Finally, Figure 7 shows that although the cognitive styles identified are not identical, they are related. In particular, all the students identified as representing problems globally were also characterized as abstract thinkers, and all the students categorized as abstract thinkers were also found to be top-down planners. Similarly, all the students identified as bottom-up planners were also identified as concrete thinkers, and all the students categorized as concrete thinkers were also found to represent problems locally. These relationships are outlined in Figure 8. In this representation, the cognitive style distinctions are paired horizontally and the arrows indicate cognitive style combinations exhibited by the students who participated in the study. In addition to the exclusionary relationships just noted, it shows that students who represented problems locally were found to be both abstract and concrete thinkers, and that students who were identified as concrete thinkers were categorized as both top-down and bottom-up planners. Likewise, students who were categorized as top-down planners were found to be both abstract and concrete in their thinking, and students found to be abstract thinkers represented problems both globally and locally.

The relationships described in Figure 8 suggest the possibility of a kind of hierarchical emergence of cognitive styles (and their corresponding problem-solving strategies) related to the development of domain knowledge. In such a view, total novices would exhibit local problem representation, concrete thinking, and bottom-up planning (and extreme forward-chaining problem-solving approaches) because they lacked the domain knowledge to structure their problem-solving otherwise. As they gained domain expertise, they would move from bottom-up to top-down planning (and incorporate alternative representation and analogy strategies into their problem-solving approaches) as they accumulated enough knowledge to consider a problem as a whole; then they would move from concrete to abstract thinking as they gained enough experience to generalize (incorporating subgoals formation into their problem-solving repertoires); and finally they would move from local to global problem representation (abandoning extreme forward-chaining strategies in favor of the more global strategies, including, at this juncture, systematic trial and error). Such a view offers a third explanatory perspective to be considered along with development (Piaget, 1971) and dispositions to particular cognitive styles (Turkle & Papert, 1990). Such a view is, moreover, most consistent with the domain knowledge, cognitive styles, and problem-solving strategies found among the students who participated in this study. As such, it deserves further investigation.

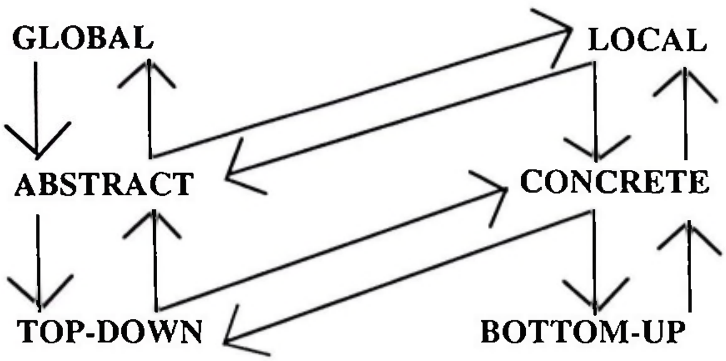

Figure 8. Relationships Among Cognitive Styles

Conclusions

While the study reported in this article is clearly very preliminary, some conclusions can be drawn from it. Perhaps the most important of these is that Logo programming can be fertile ground for the investigation of specific problem-solving behaviors (McAllister, 1990). In particular, the clinical interview-style integration of talk-aloud protocols with transcriptions of students' programming solutions seemed to provide useful insights into the domain knowledge, cognitive styles, and problem-solving strategies employed by students participating in the study. Programming problems could probably be developed that would more systematically investigate these and other cognitive areas; continued use of such methodology might prove fruitful.

Second, the study provides evidence of differing cognitive styles in participating students' problem-solving behaviors. Because of the age of the students involved (situated as they were on the cusp between what has traditionally been labeled concrete and formal operational behaviors), it is impossible to either confirm or refute Turkle and Papert's (1990) contention that such cognitive styles represent mature approaches to the world and not, as Piaget (1971) maintained, developmental stages. That varying dimensions of cognitive styles emerged from this study, however, implies that the two views may not be mutually exclusive. Indeed, a third, knowledge-based explanation emerged from the patterns of cognitive styles observed. Clearly, relationships among all three sorts of explanatory structures deserve further investigation. Repeating the study with adults would be interesting. So too would be a longitudinal study that focused on changes in cognitive styles and related these to possible changes in problem-solving behaviors, and/or an exploration of links among students' cognitive styles, their domain knowledge, and their performances on traditional Piagetian tasks.

Finally, although the current study did not explore the relationship between instruction and the development of particular problem-solving strategies, previous work (Swan, 1989, 1990; Swan & Black, 1989) has demonstrated that at least some of the problem-solving strategies explored herein can be developed through explicit instruction and Logo programming practice. The current study suggests that at least a partial explanation for the success of the intervention explored in that previous work could lie in the resulting changes in participating students' cognitive styles. That notion, and others relating cognitive styles, domain knowledge, and problem-solving strategies to specific instruction, clearly deserve further study.

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Creating a Successful Learning Environment With Second and Third Graders, Their Parents, and LEGO/Logo

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Introduction

This past year, we had the opportunity to teach a LEGO/Logo course for second- and third-grade children and their parents at the Boston Museum of Science. This article is an effort to share our observations and experience in our attempt to make the course a successful learning experience for the participants. Our main challenge was to design the course so that we were able to help seven- and eight-year-old students appropriate LEGO/Logo materials as both creative tools and learning tools. We were eager to work with LEGO/Logo and young children because we had not seen a lot of work addressing this age group. Yet, we felt the materials could support rich activities for young children. More specifically, we wanted to design a course that supported the learning of concepts in the areas of construction with LEGO Technics materials, control through the use of sensors, and programming with *LogoWriter*. A guiding principle of our design was rooted in the belief that it is not just the materials we have to think about; rather, we need to evaluate how we support the children in a way that will allow them to work independently in their chosen LEGO/Logo activity.

As a practicing teacher and a university-based researcher, we share similar views on the learning process. We believe that children develop deep understandings of ideas through creating projects that are initiated by them and are thus meaningful to them. This is part of the idea behind using the Logo programming language as a learning tool, and it is consonant with the philosophy Seymour Papert (1980) and his colleagues espoused when Logo was introduced into the schools. "Constructionism places high priority on making projects personal. It asserts that students (and teachers) who make personal connections with their projects invariably do the most creative work—and learn the most from their experience" (Resnick, 1990). Much of the work with Logo has been an effort to implement this philosophical and theoretical framework in the day-to-day lives of schools. The Logo Action Research Collaborative work that Dan and Molly Watt have been doing over the past three years supports practicing teachers in these efforts. Their work brings to the surface practical discussions of what it means to teach and learn effectively with Logo (Watt & Watt, 1991).

We asked the Boston Museum of Science if they would be interested in offering a LEGO/Logo course for 7- to 9-year-old children and their parents. LEGO/Logo classes at the museum have traditionally been for 9- to 13-year-old children. Our suggestion to teach 7- to 9-year-old children was greeted with a bit of skepticism about whether children of this age could have a successful experience with LEGO/Logo. This skepticism challenged us to begin exploring how to design the course.

We taught our LEGO/Logo course three times during the 1990-1991 school year. The course consisted of five sessions on Saturday or Sunday afternoons. We taught two sections each afternoon, with 10 students per section. Most of the students were boys and most of the parents who participated were men. The participants were predominantly from middle- to upper-middle-class, white families.

In this article, we first describe how we initially conceived of and planned the course. Next we report on our first time through the course. We then describe how we reconceptualized and redesigned the course, using our observations from this initial experience. Our strategies and goals are reevaluated as we make observations about redesigning and teaching the later sessions of the course. The summary is a sharing of the implications our investigations hold for our further teaching and research, along with suggestions that we feel we can make for primary-grade teachers who are considering using LEGO/Logo with their students.

Initial Assumptions and Planning

LEGO/Logo is a construction set that links Logo programming tools with the physical pieces of LEGO. The combination of these powerful tools can facilitate the exploration of mathematical and scientific skills and concepts. Like Logo, LEGO/Logo provides much of the same philosophical and theoretical framework to support children as they construct these mathematical and scientific concepts. Our assumption is that readers have some awareness of LEGO/Logo.

As teachers, we know that children seem to have a natural affinity for playing with LEGO and that very often their project ideas are of their own choosing. However, projects arising from their free play alone do not always lead them to discover new concepts. Our own learning experiences with LEGO/Logo taught us that the materials facilitated our learning about such things as gear ratios and leverage. These new concepts then gave us new options in our play. The resources and support we received from the instructors who worked with us were keys to our learning. Our plan was to draw from our own experience and develop a course that encouraged students to pursue personally meaningful projects. This pursuit, along with teacher guidance, would support the construction of new math and science concepts.

During the initial planning phase, one of our course objectives was to avoid disappointment that sometimes happens when young children begin to draw with the Logo turtle. Students often want to draw things that require a tedious process. Frustration may distract them before they produce something that is meaningful to them.

We felt that a similar frustration would arise if the LEGO/Logo course focus was the same for the younger children as for the older children. The themes for the older groups focused on building specific objects, such as animals, amusement parks, and vehicles. We could not expect young children to have appropriated LEGO Technics materials to the extent that the older children had. A more suitable focus for the younger group would be on exploration toward creating projects that were less specified. The theme of kinetic art helped to establish a creative and exploratory atmosphere. We expected that the students' explorations would support them in learning powerful ideas that would excite them and allow them to build more elaborate projects as they gained experience.

The First Time Through the Course

Our original course design focused on using the LEGO materials to create art. We began with a brainstorming session around the questions of "What is art?" and "What is art that moves?" We followed this brainstorming session by giving all the participants a rolling platform as a basic building block onto which they could add other materials.

We assumed that by working with students on an individual basis, they would be able to appropriate the materials and use them as tools to build pieces with different motions. We tried to involve the students in thinking about new ideas as we helped them to debug problems that arose.

The atmosphere that we established in the first class became an important part of the whole course. We set a tone of exploration during the first session. We did this by stating that, as instructors, the only overall goals or requirements we had for their participation was that they both explore and have fun. We reminded the class of this throughout the course. Some parents acknowledged that they appreciated the tone that these requirements set because it helped make the work environment less stressful.

The children's impressions of kinetic art as the "idea of art that moves" were interesting to us as an indication of their appropriation of the materials as creative tools. We developed an interview form that we used when asking children about their notions of what constitutes art, what constitutes art that moves, and how they viewed the movement of the creations they themselves had made. It seemed from these interviews that most children used the notion of art as license to create anything they wanted. But it also seemed that they could learn more about how to create different movements with the materials. With this knowledge, their creations would be more complex and their descriptions would include more about their building process.

One second-grade boy built a "wagon that rings bells while it moves." He attached bells to a wagon and when it went over a bumpy surface, the bells shook and made a sound. When asked what made it move, he said "the wheels and the computer." When asked if he had learned anything about how things move, he said "not much."

We observed that focusing on the notion of art left the specifics of how to create movements at too complex a level for the students to discover for themselves. The platform with wheels was too self-contained and bounded their thinking. Some children became frustrated, seemingly because they had not yet appropriated the materials well enough to create the kind of motion they initially envisioned. Instead of using the materials to expand their knowledge of movements, they resorted to using the materials to create movements they already knew (i.e., a vehicle that goes back and forth). Evidence for this was observed in the fact that the projects were all very similar and incorporated only one movement (rolling). It felt like the platform was not the *right* primitive procedure to start with because it didn't lend itself to building different mechanisms for movement.

We provided supplementary materials for decorating. The decorations lent some individuality to the pieces but didn't make motion a part of the artistic expression.

The questions that students were asking about creating movement with the materials centered around three main ideas: using gears to control speed, computer programming, and keeping the structure stable.

We planned to redesign the major aspects of the course based on our impressions from the interviews, our own observations, and written evaluations and informal discussions with the parents and students.

Reconceptualizing and Redesigning the Course

As teachers, we met several times during the course and prior to teaching it again to discuss participants' engagement, our own thinking about how things went, and improvements we felt we could make. The time we had to redesign the course allowed us to question our assumptions, reflect on what happened, share new ideas, and do more of our own exploration of the materials. As a result of this revision process, the course structure and focus were changed in several ways that significantly improved the experience of the participants.

One of these changes involved using the idea of LEGO/Logo primitives and searching for models that functioned in the same way as these kinds of procedural building blocks do in Logo. The other major change was in the way we structured the course (including a new introduction). The following sections describe these revisions and are followed by a brief description of other components of the course that we feel influenced its general success.

Searching for LEGO/Logo Primitives

The first major revision was a shift from focusing on artistic expression and producing a product to creating and understanding various kinds of movements and the transfer of motion. When we first taught the course, we had hoped that the simple rolling platform would be a good start for building other kinds of movement. We did not realize how complex a task it was for students to discover the variety of movements that can be created with the materials. Having realized this complexity, we looked for ways to model the different kinds of movements so that the students would, in a sense, acquire primitives that facilitate the building of complex movements.

We began our search by consulting materials that had been written for other LEGO/Logo workshops. These materials discussed creating and understanding interlocking gears, belt drives, and chain drives. These are the ideas that are faced immediately when the motor is used to drive the movement. These written materials provided clear explanations of ideas such as gearing up and gearing down (Resnick, 1987; Martin, 1990), but were more appropriate to older students. We needed materials that younger students could use to generate their own ideas about different kinds of movement. We felt these children would respond better to models that illustrated concepts, because models could represent different kinds of motion and suggest ways to extend that motion.

We played with LEGO ourselves and tried to model some solutions to some of the problems. The solutions largely incorporated the concepts of gear ratios and structural stability. Our play, along with help from Fred Martin, an experienced LEGO/Logo teacher and engineer, helped us develop models to solve these problems along with several additional models that illustrated different kinds of movement.

Instead of giving the participants a rolling platform as a building block, we shared small models of LEGO that illustrated different kinds of movement. We began to see these models as a kind of LEGO/Logo primitive analogous to primitive procedures in Logo. In the third class session, we used models built by the participants in the second class session. These models also were used in helping them to solve building problems. We used the models or built small models to illustrate ideas rather than verbally explain or build any part of their project for the participants.

The most common movements the students wanted to create were motions at different angles, up and down movements, and axle spins. We built and showed the following types of models:

- beveled gears and crown gears used to show transfer of motion at right angles
- an axle mounted through a small platform so that it could spin freely
- a universal joint used to transfer motion at different angles
- gears connected with pins or axles off-center for lopsided or up-and-down movement

A question that came up often was how to reduce the speed and increase the force from the motor. A gear assembly that does this is simple to construct, yet it is initially difficult to think through how it works. Models of motors with gear assemblies already attached proved to be valuable learning aids when students began to work with motors. They acted as a primitive embodying ideas for controlling speed and force.

We also built simple gear-train models. These models were available for students to spin by hand, allowing them to feel the difference in the force required to turn the axles.

The students built their own versions of the models and modified them to fit into their own creations. These models became the beginning building blocks, or primitives, that stimulated their thinking about concepts such as transfer of force, working with speed, and rotational motion. The models helped them build the interesting movements they envisioned and encouraged their creativity. Unlike the first course, the second course yielded many different kinds of movements that were demonstrated in the final projects.

We discovered some building tips that helped students fit the modeled motion into their work more easily and made their movement more interesting. The models we used incorporated the following ideas, which were shared with individual students on an as-needed basis:

- setting up the bricks with spacing so that different combinations of gears could interlock
- linking chain drives a little loosely, which enabled them to run more smoothly
- snapping bricks onto tractor treads
- connecting two axles together in a stable way (with the gray piston rods and flat tiles)
- using the pins to attach crossbars to make their structures more stable
- allowing enough space to allow free movement
- using spacers to hold gears in place

A New Introduction and Structure

Our redesign included a new structure for the course. The first day of the course we presented the structure in the form of a road map (see Figure 1). This clarity about the structure of the course came about largely as a result of suggestions by parents. We wanted to find a structure that would help to give the participants a sense of the ideas they would encounter. We wanted the parents to understand that the class structure did not contain a rigid set of expectations that would be used to evaluate their children's progress. The goals for the course were the same as for the first course: exploring and having fun. We emphasized these goals as we focused on each stop on the road map.

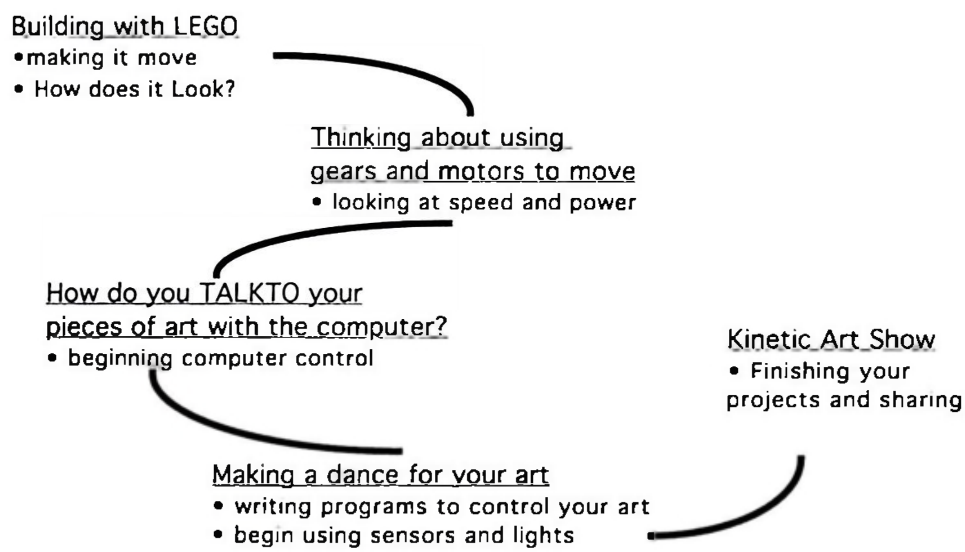

Figure 1. The Roadmap for LEGO/Logo Kinetic Art

The road map highlighted the fact that during each class a certain topic was the focus of exploration. The class topics were presented in this sequence: building with LEGO, using gears and motors, beginning computer control, and using lights and sensors. Sharing times were held throughout the course, but the last class included a kinetic art show of the children's final products. This sequence seems to naturally supply information when participants needed it in their process of appropriating the materials.

The first topic, Building with LEGO, included discussions about different movements and structural integrity. The students were first involved in a brainstorming session, facilitated by the teacher, during which different kinds of movements were listed on the board (i.e., up and down, around, back and forth, swirling, and so forth). Models embodying different movements were shared. (These models were the examples of LEGO/Logo primitives mentioned previously.) The LEGO materials were then made available, and the building began. Students were encouraged to incorporate any movement into their model.

The focus on gears and motors brought up ideas of speed and power. The gear-box models became the primitives used to work with these ideas. The hand-out for this day was an excerpt from the section on gears in the book *The Way Things Work* (Macaulay, 1988).

The concept of beginning computer control of LEGO with Logo commands was presented by telling the students that we were going to TALKTO their pieces of art with the computer. After some brainstorming with the students as to what the computer commands might be, several examples of simple programs were written on the board. Students were given a list of LEGO/Logo primitives (see Appendix A). These commands were also put on posters and hung around the classroom.

The concept of sensors and lights was introduced by using ideas made available in the LEGO TC Logo Teacher's Guide. A model light was built and used with a simple program to turn it on and off. The command FLASH was demonstrated. The touch sensor was used to turn the light on. A model stoplight (and the accompanying procedure) was used to show how a program could be written to control multiple lights and their timing. A burglar alarm proved to be an exciting way to introduce the operation of the optosensor. The students seemed fascinated with the idea that they could trigger the optosensor and cause an effect. This idea also lent itself nicely to a discussion about sensors in the real world (i.e., supermarket checkout lines, burglar alarms, smoke detectors, and so forth).

The sharing time that occurred at each session gave all the participants a structured way to share their piece of art and to talk about it. Everyone was invited to share their projects at different stages. Students often shared problems they had in trying to create a certain kind of motion. The participants were encouraged to ask each other questions. Sharing the different kinds of projects helped us see what everyone was doing and how they were thinking. The kinetic art show during the last class allowed more extensive sharing than in previous classes and was the activity that brought closure to the course. Because the class had been redesigned, students in the second course were more able than the students in the first course to talk about the motion in their project and the process of creating that motion.

Two second-grade girls made innovative projects. One created a clown face and put it on a diagonal stationary platform. She then attached a motor to its axle legs. When the motor was turned on, the clown's face shook. She named her project Clown-O and her computer procedure JIGGLE. When asked about how her ideas originated, she said that she "really liked clowns and thought jiggling would be a fun way to move." Another girl who said she had "trouble with machines" built a very complex contraption. From the beginning, she wanted to create something that moved horizontally back and forth in order to wind and unwind thread on a spool. By using and elaborating on the LEGO/Logo primitives she was able to create her vision. This project also incorporated touch sensors and lights.

Journals, Classroom Organization, and Evaluation Forms

Journal writing became a part of the revised course. Each child/parent pair was given a small notebook. We told the students that we hoped they would use these journals to ask us questions regarding problems they were trying to solve. We also encouraged them to draw pictures of their work and to write about how they felt about class that day in their notebook. Between each class we read their entries and wrote in comments. Both parents and children wrote in the journals. These journals helped us recognize specific problems that were coming up for many students as well as problems to work on with individuals. Journals became an essential data collection tool to use in reflecting on the course design. The journals helped us plan how to present each focus area, and to know what the participants' needs were. They also lessened the students' frustration of waiting for help.

The museum provided general class evaluation forms which we modified with specific questions about our course. These evaluations provided valuable feedback for us in the course revision process.

One problem with LEGO/Logo materials is that the children cannot take their projects home. We provided a Polaroid camera so that they could take pictures of their projects home. Journals and Inventor's Patents also became evidence of their work that they could take home if they wished.

The first course had one-hour sessions. It became clear that one hour was not long enough for people to become engaged in their work, accomplish interesting building and learning, and still have time for sharing and clean-up. In the revised course, the class length was increased to 90 minutes. This time period was satisfactory to meet these needs.

We found that the best room set-up was to place the building tables in a semicircle and to have the computers around the walls of the room. This arrangement made it easier to listen to presentations by the teacher, share with each other, and get access to computers.

One problem that classroom teachers often have when using LEGO/Logo in their classrooms is keeping the materials organized. We organized our materials by using a method Fred Martin had devised that worked very well for him. Building pieces were kept in big tray-like boxes and organized by color. The black and gray pieces were kept together, and the red, blue, and yellow pieces were kept together. The motors, wires, lights, sensors, battery boxes, and batteries were kept in separate boxes. This system allowed for both easy access and easy clean up.

Summary

As Resnick (1990) has noted, "Only if a workshop respects and supports a diversity of working styles will participants feel comfortable enough to work on personally-meaningful projects." In the LEGO/Logo Kinetic Art course, we tried to provide a learning environment and experience that met the needs of second- and third-grade students in creating personally meaningful projects with LEGO/Logo. We went through a progression of ways to do this and would like to continue this work in other settings. Through teaching this course, we saw how several components of the course contributed to the children's exploration and to the construction of new ideas that they used to extend their work with the materials.

We feel that the Boston Museum of Science provided us with a setting that was informal enough that we could be flexible about finding a focus for a course that was suitable for primary-grade children. The absence of curricular guidelines made it easier for us to build an atmosphere that enabled young children to play and to create comfortably. Although we found the Boston Museum of Science to be a good testing ground for developing this project, we feel that there are several implications for school classroom settings that need to be emphasized.

We think that this kind of experience would be an exciting way to involve parents in projects with their children at school. Because of the museum setting, we had the opportunity to get parents involved. We think that this is a great idea for others to try. Parents were able to give us feedback about the course that helped us a lot in redesigning it.

We suggested to each class that kids and parents work in whatever way felt comfortable. Most of the time, parents and children worked together on the child's project (parent helping child). In some pairs, the parents and children worked separately on different parts of the project and then worked together. In a few pairs, the parents made their own projects. In a few pairs, the parents mostly sat and watched. The child's learning was maximized when parent and child worked separately on parts and then later worked together, or when each had separate projects. In future classes we plan to focus on parental involvement to better understand parent/child interactions and collaborations.

We recommend journal writing and sharing times at different stages of work. We found these forms of reflection to be very helpful in supporting the experience for the participants and for us. The activities also reinforced the idea that we can all learn from each other (especially when problems and solutions are shared).

We cannot stress enough the importance of the teacher taking time to play with the materials if the teacher is considering doing this kind of work with his/her students. This was essential to our being able to create and use models as primitive procedures. Our appropriation of the materials also allowed us to make models to explain ideas that would help students in their problem solving. Handing them a model that illustrated a relevant idea kept us from being tempted to do any building for them and kept them engaged in using the idea in a way that seemed meaningful to them.

We hope that this description has offered some useful ways of thinking about setting up learning environments with LEGO/Logo for teachers who are interested in working with this age group. We believe that our course can fit well into classroom settings, with or without parents, and we intend to explore this in the future. A classroom setting could make it easier for the same children to go through the cycle of creating projects several times. Their process and products would be very informative to our areas of investigation. One area we think would be interesting for teachers and researchers to pursue in this kind of course is helping students understand sensors and the systems involved in them.

Overall, we can say that our experience helped us to see that the children's appropriation of this kind of construction set does not mean that they gain a particular articulation of concepts embodied in the materials (e.g., a knowledge of gearing up and gearing down). However, they can become aware of the principles involved in creating the projects that they envision. The evidence of their awareness of the ideas will be displayed in their building, in their choice of the ways they play, and in the methods they use to create their projects.

This project was an important exploration for us because of our interest in teaching with tools like Logo. We wanted to help learners to build new ideas for themselves through creating a meaningful product. We are pleased that this will be an ongoing project so that we can continue our exploration and our collaboration.

Acknowledgments

The idea of kinetic art was sparked for us by a workshop that Eadie Adamson (a New York City teacher) and Cathy Helgoe (of LEGO Systems, Inc.) gave at the Science and Whole Learning (SWL) workshop in 1989. The SWL workshop and the Teachers' Collaborative form a teacher-development program that helps teachers appropriate Logo and other computer-based tools and use them to think about their own learning, their students' learning, and their teaching practice. SWL is a collaboration between Boston area school teachers and the Epistemology and Learning Group at MIT, and is sponsored by the National Science Foundation under Grant TPE-8850449.

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APPENDIX A

LEGO/Logo Primitives (Martin, 1989)

BASIC MOTOR COMMANDS

TALKTO	Tells computer which ports to send commands to. Examples: **TALKTO "A** **TALKTO [A B]**
ON	Turns motors and lights on.
ONFOR	Turns motors and lights on for certain amount of time. Example: **ONFOR 30** turns on for 30 seconds.
RD	Reverses direction of motors.
OFF	Turns motors and lights off.

SENSOR COMMANDS

LISTENTO	Tells computer which sensor to use for input. Example: **LISTENTO 6**
SENSOR?	Returns value of sensor; either **"TRUE** or **"FALSE.**
WAITUNTIL	Waits until something is true. Example: **WAITUNTIL [SENSOR ?]**
RESETC	Resets value of counter to zero. Each time sensor "clicks," counter value increases by one (i.e., counts).
COUNTER	Returns value of counter.

OTHER PRIMITIVES

WAIT	Waits for a certain amount of time. Example: **WAIT 2**
FLASH	Flashes light ports on and off continuously. Example: **FLASH 10 5** will flash on for one second (10) and flash off for 1/2 second (5). Note: **FLASH** only works with *numbered* ports.
SETPOWER	Changes power level of motor or light ports. Smallest power level is 1; largest is 7.

Researching for Effective Strategies of Teaching Variables to a Fourth-Grade Logo Class

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My overall goal in teaching Logo is to provide my students with a model for solving problems. I want to provide them with opportunities to explore, analyze, and discover. And I want to introduce them to the power of the computer.

I teach at a small urban school with approximately 350 children. It is a neighborhood school. Approximately half the student population is white, while one-quarter is Asian and one-quarter Hispanic.

I have been the computer teacher at this school since its computer labs were established four years ago. I teach kindergarten and special education classes once a week, and first- through fifth-grade classes twice a week. I introduce Logo at the third-grade level.

Teaching Logo Variables

Understanding the Logo variable is a first step in utilizing the power of the computer. Seymour Papert (1980) described the idea of a variable as a key mathematical concept. He believed that symbolic naming through a variable is one of the most powerful mathematical ideas ever invented. A variable not only enables students to draw different shapes of all sizes but also supports the concept of modularity (using one procedure for more than one purpose). Thus one can recognize the source of personal power that a variable can invoke. By varying the angle in a spiral or the length of the side of a shape, students can explore various mathematical phenomena.

I wanted to discover which Logo experiences and teacher interventions would provide my students with an understanding of the concept of variables and invoke a feeling of ownership. In addition, I planned to produce a series of lesson plans for teaching the concept of variables.

My research focused, therefore, on (1) identifying the strategies that successfully enabled a group of fourth-graders to understand the concept of variables, and (2) determining the amount of teacher intervention that would maximize Logo learning while maintaining Logo's exploratory nature.

Why This Class?

I chose this particular fourth-grade class for the following reasons:

- The small class size (14 students) would allow me to observe student-student and teacher-student interactions that were more informal and more frequent than would occur in larger classes.

- Also because of the small class size, I would be able to hear the students' explanations to one another, thereby being able to determine "how they think."
- I would be able to proceed slowly and take time to clarify my directions because, according to the students' Metropolitan Achievement Test results, this fourth-grade class was made up of less-skilled learners.

Prerequisites

There was a set of Logo skills I felt the children should know before I introduced the concept of variables. These prerequisites included the ability to write a simple procedure and to write the REPEAT command to make squares, rectangles, triangles, and circles.

For example, when I asked one of my students, Marta, for the REPEAT command needed to make a square, she replied, "REPEAT 4, bracket, FORWARD some number, RIGHT or LEFT 90, end bracket," that is, REPEAT 4 [FD n RT 90]. This is an example of the type of generic command the children were taught to use whenever I asked for a shape of nonspecific size or direction. In fact, this generic command utilized the concept of variable although I had not yet referred to it as such.

In addition, I wanted to provide an environment that allowed students time to find solutions to a problem without feeling rushed. At the same time I wanted to provide all the children, particularly those who finished quickly, with some simple tools that would enable them to have fun and create new designs from previously built designs. Therefore I wanted them to know how to "spin" a shape and how to use the color tools (FILL and PenColor). Children love to spin shapes and love to fill pictures with color.

Data Collection

Meeting with this class on consecutive days, I began observing and recording my teaching activities as well as the childrens' responses and questions. I jotted notes on a sheet of paper immediately after class. I saved samples of their work on a disk and made printouts. I also looked at work done in the immediate mode and took notes of that work. In the evening I would then record a more detailed account of that day's activities.

Whole-Class Instruction

My typical strategy was to work with the whole class, first helping the students to break down the problem. Then the children worked at their seats for a short time. We regrouped to discuss problems, discoveries, and successes. The children then returned to work at their seats. Thus, seatwork became an ongoing back-and-forth process. I alternated between group discussion of problems and time for children to work solutions on their own. Instruction, practice, and evaluation were interwoven into the daily lesson.

For example, I asked the class to make a picture of growing boxes, size 10 to 40. As I walked around the room I noticed that all the children, except Scott, wrote:

```
REPEAT 4[FD  10  RT  90]
REPEAT 4[FD  20  RT  90]
```

Scott, however, wrote the first REPEAT command, pushed the Return key, and then used Control-P. With the arrow key, he then moved the cursor to the 10, deleted that number, and changed it to 20. He repeated this process until he had the diagram complete. Because Scott announced "I'm finished" minutes before anyone else, the class was curious to learn what he had done to enable him to finish so quickly. We all gathered around Scott's computer. He demonstrated how he made the growing squares using Control-P and explained, "When you do this [use Control-P], it makes the same line." (He pointed to the previous command.) "Then all you have to do is change this number." When I asked why that particular number, Kim Chi piped up, "Because that's the size." Marta wanted to know if they all could try using Control-P. They returned to their seats and completed a similar design, growing boxes from 10 to 100. I heard comments such as "This is neat," "Wow," and "This is real easy" as everyone quickly made boxes on their screen by using Control-P.

Basing lessons on students' inquiries, explanations, and desires (i.e., "I did this," "Can we try?" "Why doesn't this work?") reinforces the students' involvement in the lesson and legitimizes their participation as learners. For example, Marta asked if they could put Control-P in a procedure. And because everyone thought this was such a great idea, they proceeded to do just that. I did ask what would be a good name for their procedure. Marta suggested BOXES, Scott suggested TUNNEL, and Samara suggested MANYSQUARES. I told them to name their procedure whatever they wanted. The only requirement was that the name reflect the design so that it would make sense to another person. (We had discussed naming procedures in previous lessons, using silly names as well as sensible ones.)

Using whole-class instruction does not keep the teacher from working on a one-to-one basis when needed. However, when using whole-class instruction, the teacher must handle diversity differently. The teacher must probe and guide the students, make good use of wrong answers by having the children explain the rationale behind their methods, and generate multiple approaches to solving problems.

One good example occurred when I asked the class to write a procedure to make a square of size 80 that turns to the RIGHT. When they completed this, Samara told the class what she had done while I wrote it on the chalkboard:

```
TO SQ (Samara's name)
REPEAT 4[FD  80  RT  90]
END
```

After testing and/or fixing their procedures to ensure that they worked correctly, I asked the children to go into the editor and change their procedures so that the square would be size 30. When they had all finished, I asked which number they changed, and I made that change on the chalkboard: REPEAT 4[FD 30 RT 90]. I then waited again until the students had corrected their procedures. Evan and Melissa hadn't changed anything. Tien helped Evan get into the editor, and Marta helped Melissa move the cursor to make the appropriate change. When this procedure worked correctly for everyone, I again asked the children to go into the editor to change the size of the square to 100. I heard lots of groans, and one "Why doesn't she make up her mind?" but they were all able to make the change successfully. I also made the necessary change on the chalkboard.

We regrouped and the format of the lesson now moved into the analysis stage. When asked what we kept varying, Samara answered "the FORWARD number" and Kim Chi answered "the size." When asked for the REPEAT command to make a square, Tien answered: "REPEAT 4, bracket, FORWARD some number, RIGHT or LEFT 90, end bracket." I wrote: REPEAT 4[FD n RT 90].

I told the whole class that we could let the turtle know we would be varying (changing) the size of the square. If the turtle knows we will be changing the square size, it will look to us to put in the size (number). The turtle will, in effect, use the size we input. We discussed how varying can be done by the turtle if we simply used double dots, which I added to the "n" of our generic procedure. We also discussed the fact that whatever variable name was used in the procedure must also be used in the title name of the procedure. Because the turtle knows from the double dots and variable name that we will be changing something in the procedure, it will be ready for our input. Therefore, we wouldn't have to keep going into the editor to do the changing. Scott said a heartfelt "Good!" Kim Chi, Tien, Samara, and Marta smiled. Evan, Melissa, and Manuel looked a little confused.

While I emphasized that they were *naming* the variable, we tried all sorts of names. I wrote the names the students suggested on the chalkboard. They put the commands into their computer and then tested each procedure, for example,

Kim:
```
TO SQ : SIZE
REPEAT  4[FD  : SIZE  RT  90]
END
```

Teacher:
```
TO SQ : HAPPY
REPEAT 4[FD  : HAPPY  RT  90]
END
```

Tien:
```
TO SQ : PENCIL
REPEAT 4[FD : PENCIL RT 90]
END
```

The teacher's and Tien's variable names generated lots of laughter. The children then tried a few variable names at their seats. Some children used each others' names as a variable name. The use of meaningful names for variables is excellent programming practice. However, Clements (1988) pointed out that students often mistakenly believe that, like words, the literal symbols of mathematics are associated with fixed sets of meanings. Therefore, when children use meaningful names for Logo variables, they may believe that the name is meaningful to the computer. Clements suggested that to avoid this common misconception, the students start with meaningful names, use nonsense names as an exercise, and then return to using meaningful or abstract names. I used this technique with the students, and after giving several nonsensical names to variables, we regrouped and the class decided on a variable name that made sense. They input that procedure into their computers:

```
TO SQ  :  SIZE
REPEAT 4[FD  : SIZE  RT  90]
END
```

I then asked them to make a picture in the immediate mode with a sequential range of squares. When working in the immediate mode, all the children wrote SQ 10 20 SQ 30. However, when I asked them to put this design into a procedure, Melissa and Evan did not know what to do. Because they were both having trouble writing procedures, I worked with the two of them at one computer while the rest of the class worked at their seats.

After I finished helping Melissa and Evan, I saw that all the students had the growing square design on their screens. However, they had used three different approaches to achieve the same result. Manuel and Tien again did the design in the immediate mode. But Scott, Heather, and Margorita wrote:

```
TO SQUARES
REPEAT 4[FD  10  RT  90]
REPEAT 4[FD  20  RT  90]  ....
```

The remaining children had used the following subprocedure and variable technique:

```
TO SQUARES  (Marta's name)
SQ 10
SQ 20
SQ 30
SQ 40
END
```

We discussed how everyone had completed this project. When I asked Tien and Manuel why they did the growing squares in the immediate mode, they said, "because you can't put this [SQ 10 SQ 20] in a procedure." Scott, Heather, and Margorita agreed with them and explained how they had reverted to the "long" way to solve the problem. Marta said, "Oh, yes you can" and read her solution (see above), which I wrote on the chalkboard. Samara said, "I did mine different. I wrote: TO BOXES, SQ 100, SQ 90, SQ 80." I wrote Samara's solution on the chalkboard as well.

Those children who had exhibited difficulties expressed surprise at Marta's and Samara's solutions. We stopped for a moment to reflect on the extensibility of Logo, which allows us to create our own Logo words (SQ : SIZE) and then use these new words to build additional commands.

Those who needed to used Marta's or Samara's solution. A few chose their own name for the superprocedure. Scott named his procedure TUNNEL; Manuel named his procedure HALL.

Sharing

The pace of this class was very slow. We had time to admire discoveries, write those discoveries on the board, and have others try them. The discoveries made by spinning various shapes and using pen colors produced wonderful and exciting designs. The children were enthusiastic and shared their discoveries with the entire class. If they liked a particular design, they wrote the commands in their Logo notebooks.

Providing time for children to explore their Logo microworlds to make discoveries is an integral part of the Logo philosophy. Children love to learn from one another. It is not unusual to hear, "How did you do that?" or "Can you show me what you did?" or "Wow, look at what I made!" Collaboration is a natural component of the Logo environment that I encourage and utilize.

Students develop responsibility for learning by sharing what they learn. Providing them with opportunities to share is a vital part of learning. It allows them to join in the communication of learning. It helps some to find their own voice. They become active learners.

If they wished, children who had a problem used someone else's discovery and soon were spinning and filling in designs, all the while using a procedure with an input. Other children would elaborate on someone else's discovery. Often, new questions and new answers would arise from someone else's discovery. For example, Melissa and Heather explored adding various pen colors to their procedure BOXES. The procedure BOXES used the subprocedure SQ : NUM. When they used pen color 6 (reverse white and black), they created a wonderful design.

The girls were very excited with the result and shared it with the class. The class tried using pen color 6 and got the same result. There followed lots of theorizing about why the graphic looked the way it did. Tien asked, "How can the color be black and white?" Kim Chi said, "It's erasing some of the picture." When Bobby asked, "How can it do that?" Kim Chi said, "Watch." She ran the procedure again, beginning with PC 6. Then she said, "See, it's writing, now it's erasing. See?" After more theorizing, they looked to me and asked two questions: "Is it [Kim's theory] really doing that?" and "Why?"

Answering Tien's question about how a color can be black and white, and utilizing Kim Chi's discovery of erasing, we discussed the meaning of "reverse pen color." The turtle writes in the reverse color of the screen it is walking on. Hence, if the screen underneath the turtle's pen is white (a previously drawn white line), it will draw in black. Because you can't see black on black, it appears to be erasing the line. If the screen underneath the turtle's pen is black, it will draw in white and a white line will appear.

By working together and discussing possible solutions, the children were able to find the answers to their questions faster and more easily than if they had worked alone. We need to provide an environment where children learn to work cooperatively to solve new problems. Logo provides such an environment, where students are encouraged to share their knowledge, insights, discoveries, and strategies.

Using Kim's theory, and with some help from the teacher, the children together worked out the meaning of reverse color and made it their own. This occurred because Heather and Melissa shared their discovery, and because the class talked to each other about what they thought was happening.

In the following 10 class meetings, the students made growing triangles, growing circles, and growing stars. Children who were successful with their growing shapes would explain their procedures, and I would write them on the chalkboard.

Those having difficulties could use those solutions. These children also received help on an individual basis from me or from a classmate. Because the only difference was the shape that grew, the children were able to focus on the concept of one variable. Since the shapes were different, the designs produced by spinning were different and kept their creative juices flowing.

The most common problem was that the children tended to forget to include the variable name in the procedure title. When we first began using one variable, half the children needed help. When we finished, all but Evan were able to use one variable comfortably without any teacher or peer assistance.

We progressed from using a single variable in a single shape to using a single variable with two or more shapes to form one picture. It was at this point that I stopped to reassess the method I was using to teach procedure writing.

Tell Me in English

I asked the class to tell me how to make a house, and Kim Chi was the only volunteer. She immediately gave me the Logo command REPEAT 4 [FD 50 RT 90]. When I asked "What next?" the children looked confused. Marta hesitantly volunteered, "FORWARD 30?" and looked at me quizzically. No one else volunteered. I was surprised because the students had made simple houses and other two-shaped pictures in third grade. Where was the enthusiasm and self-confidence I had come to expect?

Upon reflection, I realized that in the past, whenever I presented a specific Logo project to my students and asked them to tell me what must be done, the few responses would consist of hesitantly given Logo commands (i.e., FORWARD 50, RIGHT 35). Because most of the children did not know the exact angle to turn the turtle or exactly how far forward or backward the turtle should move, they would not volunteer a response. This tendency to answer in Logo resulted in many students believing that they did not know how to do the project and that they were not good enough at Logo. These same children had no problem making a simple design, or experimenting and discovering wonderful pictures. Yet when asked to do a specific design, they would think it was too hard.

Why this was happening? Was the problem that the children were trying to think exclusively in Logo ? Could they answer my questions and complete a project if they thought out the entire process in English first? How would I facilitate this strategy?

When Seymour Papert (1980) stated, "In order to learn something, first make sense of it," he was referring to the idea of "playing turtle." Playing turtle is the physical way to make sense of something. A nonphysical approach might be to first write what the turtle should do in your own language and then translate those directions into Logo (turtle talk).

Therefore, I rephrased my original question to the fourth-grade students. I asked them to tell me in English how to make a simple house. Whenever I received an answer that was in Logo (i.e., FORWARD 50), I would re-emphasize that I wanted them to tell me in English exactly what they wanted the turtle to do. Acceptable answers would be: "Move the turtle to the top of the square" and "Move the turtle up."

After the children understood what I meant by "Tell me in English," more than half the class eagerly volunteered to tell me what the turtle should do. I wrote their English directions on the chalkboard under a column headed "English." At the same time I tracked the turtle's progress with a piece of chalk on the chalkboard. After all the directions were given in English, Bobby and Heather translated the English commands into Logo commands. I wrote the Logo commands next to the English commands under the heading "Logo." (Heather chose 30 to be the size of the square and triangle.)

Although we did not discuss its meaning at this time, I required the students to draw a state-transparent shape. State transparency is when the turtle ends back in its starting position (same location and same heading from which it started) without employing the primitives HOME , SETH, or SETXY. State transparency is good programming advice. It makes it easier for the student to use the shape in larger projects. It allows for easy movement of the shape to other locations on the screen. (Spinning designs provide excellent practice for using this technique.)

This "Tell Me in English" process reinforced the concept that Logo is a language. It also taught the children to think about the whole picture first. They did not get hung up on exact Logo commands. They were able to reduce their assignments into bite-size pieces, working comfortably in their own language. The children worked first on what the turtle should do, and then on how to get the turtle to do it.

After the children input the Logo procedure and tested it, I asked them to make a smaller house of size 20. Their responses included comments such as "How do you do it?" and "What do we change?" My answer to them was, "Change what you think, and try it out. If it doesn't work, type DRAW and try again." Manuel forgot to change the command that made the triangle size 20. However, when he tested his procedure and saw his error, he immediately went into the editor and fixed it. On the other hand, Margorita did not solve her problem quite so quickly. She could not understand why her procedure wouldn't work. I suggested that she read the English directions and at the same time track those directions on a paper. I watched. When she turned right, I asked why she was turning the turtle 30 degrees right. She answered, "So the roof sits on the house right." When she turned the turtle left, I asked, "Why turn left? Last time you turned right." She explained that because she turned right the first time, she had to do the opposite now. Then a huge smile appeared on Margorita's face. Her eyes lit up, and she declared "I know now." I was in the middle of asking her how many degrees she should turn the turtle, but she just waved me away as she busily went into the editor to make the necessary changes.

During the remaining class time, some of the children created designs using the HOUSE procedure. Marta tried spinning the house. She loved the results and asked if she could put the spin in a procedure. She named her procedure WINDMILL. Others liked her design and asked for the directions. Her design was duplicated, elaborated on, and shared by others. Bobby, Melissa, and Samara made two to four houses on the screen in the immediate mode. Then they filled them with various colors.

Some of the fourth-grade students used the concept of modularity. For example Marta's WINDMILL used the HOUSE procedure to create a design that was not a house. Kim Chi made two houses on the screen, one large and one small. After making the small house she went into the editor and changed the size to 50 and renamed the procedure LARGE. HOUSE. She did not attempt to write a procedure using the concept of variable. When she needed a larger house, she wrote another procedure named LARGE. HOUSE rather than write a procedure with an input.

I observed that my students did not use the concept of variable unless required to do so, nor did they naturally use the concept of subprocedures.

Why? Could it be that children work in such small chunks they do not see the overall picture? Or could it be that even if they do see the overall picture, they do not look for similarities or patterns? Maybe it is simply that at this age they are very exacting creatures and when they want a small house, they write a procedure named SMALL. HOUSE.

According to Clements (1988), researchers have found not only that students rarely choose projects that need the concept of variable but that they also resist using the variable concept even when it is suggested. He cited other researchers who introduced the variable concept through procedures that take inputs. These researchers found that neither of these concepts arise spontaneously and that a high degree of organized instruction and elaboration was needed. My observations concur with these findings.

Using Inputs Within Subprocedures

Because I wanted my students to realize the power that the variable concept generates, I assigned tasks that required its use. For example, I requested that they write a procedure to make a house of any size. (Later I assigned a project to create a town where every house needed to be a different size.) Working as a whole class and using the "Tell me in English" process, the students gave me the following directions, which I wrote on the chalkboard. With a few judicious questions (for example, "Is the square going to always be the same size?"), I extracted the answer that it could be of any size.

ENGLISH

TO make a HOUSE that can be any size
Make a SQUARE that can be any size
Move the turtle to the top of the square
Turn the turtle RIGHT 30 degrees
Make a TRIANGLE that can be any size
Turn the turtle LEFT so it is straight up

Move the turtle BACK to the bottom of the square
END the procedure

I also asked the students to write procedures for a square and a triangle, as well as a procedure for a house.

Watt (1988-89) has shown, and my own observations confirm, that students don't necessarily learn to use subprocedures without some type of teacher intervention. As the students began to input the procedures, they soon realized that to make a square and triangle any size they had to write procedures using the concept of variables. Next they had to use these two procedures as subprocedures in the superprocedure HOUSE.

Bobby was first to complete this assignment. He was thrilled because this was first time he had completed an assignment before any one else in the class. Calling me over, he proudly explained his picture. Pointing to each house, he said, "This is HOUSE 10, HOUSE 20, HOUSE 30, " and so forth.

```
TO HOUSE : SIZE
SQ : SIZE
FD : SIZE
RT 30
TRI : SIZE
LT 30
BK : SIZE
END
```

The children who completed this assignment made a little town, displaying three or four different-sized houses on their screens. Kim Chi was the only student to record her work and write a procedure.

After several lessons using variables to write procedure designs with more than one shape, it was time to use two variables within one procedure. This transition happened quite naturally and at the students' request. Because it was February, the students decided that they wanted to make valentines. However, when they began to work on this project, I heard them ask, "But how do we begin? What should we do first?"

Finding a shape they recognized in the heart shape (half circle), the class worked together to write procedures to make hearts of any size. First we wrote the instructions in English, and then we translated them into Logo:

ENGLISH	LOGO
Make a half circle	HALF.CIRCLE :NUM
Turn the turtle straight up	RT 180
Make another half circle	HALF.CIRCLE : NUM
Turn the turtle right	RT 30
Make a line	FD
Turn the turtle right	RT 110
Go forward	FD

I supplied the students with the degree of the angle for the turns (30 and 110) after they had experimented on their own. I intervened here because it was February and they only had two classes to produce valentines. However, I did require that they discover the length of the sides. I told the children the length would be the same for both sides of the heart. First the class tried to find the SIDE.LENGTH needed if the HALF.CIRCLE size was 3. After the class worked for several minutes, we stopped to discuss what they had discovered. Tien and Marta discovered that the SIDE.LENGTH should be 60.

The class then worked to discover the SIDE.LENGTH for the HALF.CIRCLE4. Manuel and Patsy found the SIDE.LENGTH would be 80. Everyone tested it while I added these discoveries at the chalkboard under two headings:

HALF.CIRCLE	SIDE.LENGTH
3	60
4	80

When I asked the students to find the SIDE.LENGTH for a HALF.CIRCLE 5, Scott immediately said, "It's 100." I wrote that under the appropriate headings. The class tried it, and it worked. When I asked Scott how he had figured that out, he said, "Well, before that it was 80 and before that it was 60, so it had to be 100 now." I asked if he meant that each time we increased the HALF.CIRCLE size by 1, the SIDE.LENGTH increased by 20? He said, "Yes." The students nodded their heads in agreement. Therefore, I asked, "If what we just said was true, what would the SIDE.LENGTH be if the HALF.CIRCLE was size 2?" Kim Chi immediately answered "40."

When we finished, the chalkboard looked like this:

HALF.CIRCLE	SIDE.LENGTH
1	20
2	40
3	60
4	80
5	100

Pointing to the chalkboard, I asked them to write a procedure that would make a heart of any size. Kim Chi's procedure looked like this:

```
TO HEART : N  :S
HALF.CIRCLE :N
```
(:N meant "any number")
```
RT  180
HALF.CIRCLE :N
RT  30
FD  : SL
```
(:SL meant "any SIDE.LENGTH")

```
RT  110
FD  :SL
END
```

Without exception, everyone had used two variables. Marta named hers : SIZE and :SIDE. Tien named his :N and :S. When I asked why they had two different names for the variables, Kim Chi explained, "First you have the circle size, then you have the length of the sides, so you need two different names." The class made valentines, using their procedure with two variable inputs.

Although the children had successfully achieved their goal of making valentines, I used this procedure as a stepping-stone toward working with proportional variables. This heart procedure provided an ideal opportunity for the children to gain an important mathematical concept.

Proportional Variables

Using Logo variables with mathematical operations paves the way for understanding the algebraic concept of an *unknown*. The idea that we can name a piece of information, manipulate that information symbolically without knowing exactly what it is, and substitute a specific value later is one of the prerequisites for understanding almost any branch of mathematics (Watt, 1988-89). We worked from the known to the unknown. ' put the following on the chalkboard:

HALF.CIRCLE		SIDE.LENGTH
1—20	=	20
2—20	=	40
3—20	=	60
4—20	=	80
5—20	=	100

I pointed to the work on the chalkboard and said, "We know that a HALF.CIRCLE of size 2 (fixed value) needs a SIDE.LENGTH of 40 (fixed value), and a HALF.CIRCLE of size 3 needs a SIDE.LENGTH of 60." I then said, "We also know every time we increased the HALF.CIRCLE by 1, the SIDE.LENGTH increased by 20." I then asked, "Which one arithmetic operation (plus, minus, multiplication, or division) would give those answers?" The children were given several minutes to discover the arithmetic operation that would hold true for all answers. Several discovered the operation almost immediately. (Everyone first tried addition.) However, Manuel announced quite loudly, "It's times: you have to multiply."

Using this experience as a starting point for further learning and applying it to what they already knew, I asked the students to write a procedure that would make a heart of any size. I recommended that they use the formula of "times 20" (*20) and add it to their procedure wherever needed. Kim Chi worked alone. Tien and Manuel, Margorita and

Patsy, Marta and Samara, and Heather and Melissa worked together. They all were successful and wrote similar procedures. The following one was written by Marta and Samara:

```
TO HC :N
(HC meant "half circle")
REPEAT 28 [FD  :N RT 10]
END

TO HEART  :N
HC  :N
LT 180
HC : N
RT 30
FD  :N*20
RT 110
FD  :N*20
END
```

The class was pleased with the results. This idea of proportion is a difficult concept and one they wanted to share. Logo-generated valentines and hearts permeated the computer lab and outside bulletin board during the month of February.

This project ended a 14-week period in which I emphasized the concept of variables with almost every project we constructed.

Conclusion

My classroom research has shown and outside readings have supported the idea that children generally do not learn the concept of variable on their own. Some form of teacher intervention is needed. But there is no general consensus on the form or degree of such intervention. Studies have shown that Logo environments that are too loosely or too tightly structured may not be effective (Clements, 1989).

I designed lessons to emphasize the concept of modularity. After they could write one square procedure, they could use that square procedure for the base of a house, two windows, and a door. The students discovered that it was easier and faster to create a growing triangle by writing TRI 10, TRI 20, and so on than by writing several REPEAT commands. I designed lessons to utilize the concept of a proportional variable (i.e., the valentine/heart lesson).

I found that by creating a variety of lessons specifically designed to use the concept of variables, children were able to successfully understand and incorporate this concept into their Logo knowledge. I also found that by designating a block of time to this one concept, the children had ample opportunities to explore, discover, and become comfortable using variables.

It was interesting to observe how students designed their own projects. If they decided to use the concept of a variable, it was for a specific graphic (i.e., fireworks, snowflakes). For example, when Marta and Samara created a picture with a snowman and a full moon in the sky, they wrote two circle procedures. (They had discussed whether to have the moon as big as the snowman's head or as big as its bottom). However, when they decided to add stars, they talked about making the stars different sizes. So they wrote a star procedure using one input.

I was able to focus on my teaching method. Although the lessons were structured, they were not rigid. Time was provided for free exploration and discovery. Children were able to share, for example, Scott's demonstration on using Control-P—"First you type this then you do this [push Control-P]," he said. Time was provided to discuss theory. For example, the children questioned why Heather and Melissa's picture looked like it did. Because of the girls' discovery and the discussion that followed, the children were able to define reverse pen color. Although lessons were structured, they were open-ended, providing the opportunity for students to become very active participants, for example, Marta's "Can we make this [write] a procedure?" with the growing square).

My teaching strategy—the whole-class approach—begins by first introducing or reviewing a specific objective with the entire class. Next, students work at their seats either alone or with partners to try to solve the problem presented. Then we regroup, and as a whole class discuss successes, discoveries, and problems. This time becomes a time to share and to hear. Because time is provided to listen, I am able to hear students' rationales for doing what they did. Misunderstandings are clarified. Errors are not considered as something to hide but rather as wonderful opportunities to discuss why something happened. It also is a time to realize that some of their mistakes or accidents made wonderful designs. (These were written in their Logo Discovery booklets for possible use at a later date.)

I also made my own discovery. I discovered the "Tell Me in English" method. It enhanced the effectiveness of my Logo teaching and the learning process in my class. The "Tell Me in English" approach proved to be a wonderful way to teach the writing of simple procedures and of superprocedures. It clarified and simplified procedure-writing by allowing the children to think through an entire project in their own language before attempting to write it in Logo. It allowed the children to concentrate on what the turtle should do because they were not having to simultaneously translate their thought into another language. The "Tell Me in English" method has become an integral part of my Logo teaching.

Logo provides a natural environment that encourages cooperative learning and communication. It is a wonderful tool to teach the process of learning, thinking, and problem solving. Just as there are a variety of strategies one can use to arrive at a solution, there are a variety of approaches to teach and learn Logo. The processes the students use to create a product is, in the final analysis, more important than the product itself.

Acknowledgments

I joined the Logo Action Research Collaborative (LARC) in 1989. As a computer teacher in the city of Boston and as a Logophile I was excited by the prospect of meeting with other teachers to talk about Logo. We met throughout the school year. We assessed

our students' Logo learning, discussed various strategies, and investigated the benefits of Logo learning. It was a wonderful year. Thank you to my fellow LARCers.

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The Effect of One Logo Learning Environment on Students' Cognitive Abilities

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Introduction

This article describes a collaborative university-elementary school research project in which we investigated how the use of *LogoWriter* affected students' cognitive abilities. The present authors—Karin Wiburg, a university researcher interested in the effects of computers on students' thinking and problem-solving abilities, and María T. Fernández, a computer-using teacher—met in 1986. Fernández had been teaching elementary school children Logo for several years. She was interested in action research and taught in a school with a principal who was happy to provide a site for this study. Based on our personal experiences of working with Logo, we believed that programming had positively affected our own thinking as well as the thinking of the students we had worked with, yet we were challenged by the lack of research data to support our beliefs. We were determined to look more systematically at what seemed to be working well in the Logo classes at Park Dale Lane Elementary School and to develop a joint research project.

Programming as Design

The literature suggests a mixture of conflicting results concerning the relationship between programming and cognitive gains (White, 1985). However, significant gains in both academic achievement and thinking strategies have been reported when programming activities were skillfully integrated with the school curricula (Firedog, 1985; Clements, 1986; Shore, 1986; Wiburg, 1987; Au, Horton, & Ryba, 1987). The way in which these studies conceptualized programming was different than in earlier studies in which the purpose of teaching programming was to train programmers. Instead, environments such as *LogoWriter* were being conceptualized as tools for thinking about concepts taught in the academic curriculum.

Newer tools such as *HyperCard*, *LinkWay*, *LogoWriter*, and *HyperStudio* provide powerful icon-oriented environments for creating and manipulating objects using the computer. In fact, it could be argued that these new languages are so different that previous research on the potential cognitive impact of programming may no longer be relevant.

In addition, at the time of this work, there was recognition that programming languages have changed fundamentally (Balzano, 1987; Bork, Pomicter, Peck, & Velaso, 1985). These newer languages were more like creative design tools than the mathematically-oriented, sequential coding environments of early days. Bork and colleagues suggested a merging between productivity applications, such as word processors and spreadsheets, and programming languages. Good applications software included an aspect of programmability, such as using macros or command files, while newer programming environments include good word-processing editors. This suggests a merging between the traditional separation of computer functions into either "tool," a program to produce with, or "tutee," a program in which the learner learns by giving instructions to the computer (Taylor, 1980).

According to Nastasi, Clements, and Battista (1990), research comparing Logo to a set of utility and problem-solving programs demonstrated that stronger feelings of control of mastery emerged with Logo. They concluded that, of all the programs reviewed, only Logo provided a coherent intellectual tool. One meta-analysis showed that studying Logo had stronger overall effects on problem solving than did studying other computer languages (Liao & Bright, 1989).

According to Clements (1990), there are two ways of using Logo: the "exposure approach" and the "conceptual framework approach." Research on the conceptual framework approach, in which students learn enough Logo to add Logo concepts to their mental frameworks, shows the most positive effects. Appropriate use of Logo, for example, helped students analyze and understand the properties of geometric figures (Clements & Battista, 1989; Clements & Battista, in press).

One of the surprising research results is that the largest, most consistent benefits occur in the social and emotional domain (Clements, 1986; 1990). Many teachers and administrators make decisions about software use based on its potential for giving students short-term cognitive gains. However, instructional environments such as programming with *LogoWriter* (which has powerful and beneficial long-term effects) may provide more educational power for students in the long run.

An Instructional Model for Computer-Based Problem-Solving

In addition to using a new computer programming environment that provides control over graphics, sound, text, and numbers, we were interested in applying an instructional model for facilitating problem solving. We suspected that there was something about the way we had been teaching Logo to children that was contributing to their success. Gallini (1985) suggested an instructional model and specified two conditions necessary for teachers to develop computer-based problem-solving environments. First, students should use programming to ask and answer questions about the content they currently are studying. Second, students must be helped to learn and articulate the problem-solving process while investigating concepts in such an environment. Therefore, our collaborative research was designed to make sure students were engaged in programming activities that were about the content they studied in their classrooms, and to directly teach students both problem-solving and programming strategies.

The Research Design

Our approach was to determine what the fourth-grade teachers participating in the study planned to teach between January 1986 and July 1986. We then selected a number of those topics to be taught that we believed could be better understood with the use of programming activities. These topics included fractions, symmetry, word problems, whales, the Gold Rush, and United States geography. Students would be asked to design products that exhibited understanding in these chosen content areas. The emphasis on design runs through our work and reflects an important perspective on the goals of the curriculum, as well as a possibly optimal application of new programming tools.

Eisner (1985) suggested that if we want to teach problem-solving behavior, we must change from having behavioral objectives to having problem-solving objectives. Such problem-solving objectives, like the design projects we suggested to students, provide criteria for successful solutions but do not dictate the form in which students might reach these solutions. For example, students were asked to design a scene from the Gold Rush using *LogoWriter*. They were given a goal and taught some specific strategies for both problem solving and programming. As problem solvers, they learned to organize information about the Gold Rush, think divergently about the sorts of environments in which the miners lived and worked, and use brainstorming techniques to arrive at possible solutions to problems these miners must have faced. (One of the more successful projects was the design by the whole class of a floor-to-ceiling flowchart that showed the branches of an adventure story about the Old West.) In addition to mastering flowcharts and other planning procedures, students learned how to write Logo procedures to control the presentation of different scenes in their stories, to program graphics and animation, and to customize their own shapes for use in story scenes.

Establishing Groups and Starting Our Classes

Students at the school normally attended the computer lab in the media center twice a week for approximately 40 minutes per session. They arrived in half-classroom sized groups (approximately 15 students). We kept these naturally occurring groups but were able during the time of this study to increase the computer lab time for the groups we were working with to approximately two hours per week.

In addition to the *LogoWriter* group, we decided to have a second group that also engaged in problem solving and used word-processing and simple graphics programs. We had conceptualized the writing process as being similar to the programming process. Students who write also must plan, type (or code) in their program, test or critically evaluate their output, and then revise and debug. We were interested in whether a programming environment such as Logo, which provided more control over objects (both text and graphics) and demanded more cognitive processing than the applications programs, would have more positive effects on students' thinking. Finally, a third group served as a control group and continued to attend the regular computer sessions, which involved work with applications and quality CAI software such as that developed by MECC and Sunburst. The pretest and posttest design is shown in Table 1.

Both experimental groups (Group 1 and Group 2) worked on content related to the curriculum and were explicitly taught problem-solving strategies. The groups were not made up of randomly assigned individuals; however, we did randomly assign half-classroom sized groups to one of the larger groups for the study. The research took place

Table 1
Pre-post Test Design for Study

Group 1	Pretest	X1o	Posttest	N = 25	*LogoWriter*
Group 2	Pretest	X2o	Posttest	N = 25	Applications programs
Group 3	Pretest		Posttest	N = 22	Control

Group 1 received treatment X1 = instruction and practice using *LogoWriter*, a programming environment; Group 2 received treatment X2 = instruction and practice using word processing and graphics, an applications environment; Group 3 served as the control group. The lowercase o's indicate continuous observation of the students by the researchers during the study.

at a year-round school between January and August, 1986. One of the present authors María Fernández, was the teacher for all the students, while the other author, Karin Wiburg, worked as a participant observer. After the first couple of weeks, Wiburg ceased to be a novelty and could observe students closely as they worked at the computers.

Data Gathering and Analysis

We planned from the beginning of our research to use qualitative as well as quantitative approaches because standardized tests often do not measure whether students really are accomplishing what we want them to accomplish, such as improving their problem-solving abilities. We also took into account that it is difficult to achieve much change in a year or less. We kept notes, talked each day about what occurred, interviewed students, developed an observational checklist, and collected products.

Students were pre- and posttested on the Developing Cognitive Abilities Tests (DCAT), a test designed to measure changes in higher level cognitive skills as defined by Bloom's taxonomy (application, analysis, and synthesis). The mean gain scores for all groups on the total and subtest of the DCAT were compared using an ANOVA.

Products were collected and evaluated using a researcher-generated product assessment scale, based on Table 1 in the California Assessment Program's Writing Test. The modifications included adding two components: one to evaluate creativity and one to look at the effectiveness of the use of graphics with text. Six English teachers (two college professors and four public school teachers) served as evaluators of the student products.

While observing students in the lab or reading over the day's journal entries, we asked ourselves what specific behaviors might be indicative of the higher level cognitive skills being investigated. An observational checklist, based on Table 2 in the California Assessment Programs's Writing Test, was slowly developed and modified several times.

Findings and Implications of This Study

There were no statistically significant differences in cognitive abilities between groups on the pretest as measured on the DCAT. However, at the end of the study, significant and positive differences did exist in the mean gain scores on the areas of the DCAT designed to measure higher level thinking. Students in both the *LogoWriter* group and the applications group scored significantly higher in these areas than did students in the control group. Ironically, when the scores were further compared for all areas of the DCAT (including lower level cognitive skills such as knowledge and comprehension) the *LogoWriter* group scored significantly higher on these lower level cognitive areas when compared to the applications group. Our observations indicated that students were often engaged in mental arithmetic as they constructed their Logo projects. This may have resulted in the strong gains in simple computational skills, which translated into significant and positive differences in knowledge skills when the *LogoWriter* group's scores were compared to the other groups' scores. We were pleased with this unintended result: more basic skills with no drill!

Evaluations of student products by the English teachers indicated no significant differences in terms of the appeal or level of interest in the message or covergent production (a measure of clarity and conciseness of the message), but significant and positive differences did exist in divergent production. The products produced by the students using *LogoWriter* were judged to be more creative.

Toward the end of the study, a teacher and a parent who were unfamiliar with the study were asked to use the observational checklist to observe groups. Differences were noted primarily in two areas: more interaction with peers occurred among students in the *LogoWriter* group as compared to students in the word-processing classes, and more students were on-task in the Logo group.

The results of this research are quite promising. The similar positive growth in cognitive abilities among students in both treatment groups indicates the power of an instructional model that integrates computing with the content of the school curriculum and explicitly teaches problem-solving strategies. While the emphasis in teaching programming has been more on the process (what students learn from programming) than on the product, it is interesting to note the indications of greater creativity by students who used a more challenging tool such as *LogoWriter*.

However, caution is indicated. There were some unusual conditions present. Both the university researcher and the teacher had a strong background in Logo, and the students also had some previous Logo experience. Logo had been introduced to students during kindergarten and they were therefore ready to develop procedures and use variables. We also worked with 15 students at a time as compared to the average 30-student class. Not all schools are able to have teachers with this level of knowledge or to support computer use with qualified facilitators throughout the curriculum.

Exceptional Diversity

The findings in terms of creativity are further reflected by work Fernández did alone during the same period we were working on the research project. She was working with five sixth-grade students from the same school that participated in the Logo project. These students were doing eighth-grade math in their classroom and came to the computer lab for enrichment activities in math. When asked what they would like to do with computers, they all expressed the desire to use Logo. They had worked with Logo in previous years and had some programming skills, including the ability to write procedures with variable inputs, use conditional statements, and create superprocedures.

These five students in the Gifted and Talented Education (GATE) program found five different ways in which to express their creativity through *LogoWriter*. They were all gifted, but in quite diverse ways. In only a matter of months in the *LogoWriter* environment, these students were able to develop and synthesize products that reflected their diverse interests and abilities. Their work also reflected the differences in their thinking styles and their preferences for either a graphics or text environment. A brief description of three of their programs illustrates the ability of the Logo environment to provide extensible and divergent applications that meet the needs of the learner.

Boards on Earth and Water. This program deals with skateboarding, surfing, and skiing. To create this program the author needed 21 turtle shapes. Boards on Earth and Water has three linked pages: Picture, Launch, and Tubetime. The product is an animated short subject.

Adventures of Ebo. This is a touching story of an alien and a human boy. The story contains 13 pages, some of which have text only, while others have text and graphics. All the pages are linked so that the display goes from one page to the other without stopping. One of the pages includes music.

Animated Alphabet. The author developed this program to teach the letters of the alphabet to kindergartners at the school. Animated Alphabet contains animated turtle-shaped pictures for all the letters of the alphabet except X, Y, and Z. (The author said he couldn't think of any pictures for these letters.) This program beautifully combines text, graphics, and animation.

Other Studies Using Logo and the Curriculum

We have continued to share our work with our graduate students in computer education and in curriculum and instruction at the United States International University in Southern California. The following is a description of one of these graduate students' work.

Gwen Tegantvoort is a kindergarten teacher who created a program using *LogoWriter* that she hoped would help her students to learn directions. The problem she investigated was whether using a Logo graphics program would help her students to master the reading-readiness skill of left-to-right progression.

The subjects for her study were kindergarten students in a lower middle class elementary school in Buena Park, California. Two of the four kindergarten classes used her program. These students had been placed randomly in their respective classroom groups at the time they entered kindergarten. Both control group and treatment group classes were given a pretest in April 1991 and a posttest in June 1991. A printed copy of the highest level of the Razzle Dazzle Maze Craze Program, which Tegantvoort developed, was used as the testing instrument. Students were asked to indicate the starting place and to show the direction a cat should use to get through the maze.

The control group's test scores stayed the same on both the pretest and the posttest. In the control group of 28 students, 4 students could not pass the test at the beginning or the end of the study. Of the 31 students in the treatment group, 7 were unable to pass the pretest. These students were then given the opportunity to work with the Logo program. At the end of the study, all students in the treatment group who had worked with the maze program passed the test. In fact, Tegantvoort reported that these students were so anxious to take the posttest that they could hardly wait for the directions to be given.

Plans are now underway to give all kindergarten students access to this program next year. The teachers believe that with this assistance the students will not only be more successful in mastering directionality but also will be more comfortable with the early reading exercises now required in the public schools.

Questions and Issues

The emphasis in this article has been partly on test results that demonstrate the effectiveness of Logo and Logo environments to improve student achievement levels. We are not primarily interested in teaching in ways that meet current testing criteria because we believe many of these tests are measuring the wrong things. However, we are realists, and if using Logo can help students to score better while they are enjoying learning and learning to think, we think it is pragmatic to report these results. Three issues that grew out of our work are worth further discussion.

The Centrality of the Teacher

We think our positive results are related to the knowledge we had of Logo and our ability to develop and deliver lessons that helped students develop problem-solving skills. Powerful tools are necessary but are not sufficient for good results. An interesting question to ask is: What kind of organization must schools have to allow the level of teacher expertise and the kind of small-group interaction that occurred in our study? We think such environments are possible within the public schools; in fact, the school in our study was a public school, but it tapped into affiliations with universities and community resources.

The Need For Instructional Models That Integrate Tools and Concepts

The students' use of *LogoWriter* and applications software to explore and create while learning the concepts being studied in the elementary curriculum may have been the most important aspect of this study. The fact that students gained basic skills while creating and thinking is interesting. A year after the present study, Karin Wiburg and Jerry Balzano, a professor from the University of California, San Diego, worked with *HyperCard*, social studies, and language arts in four sixth-grade classrooms in a different public school. The results were similar and positive.

How can we develop these teacher-, student-, and curriculum-based models? Would it be better to invest our money in computer curriculum specialists in the schools who would work directly to assist teachers rather than investing in the integrated learning systems currently in vogue? While we see the need to integrate new tools and teaching strategies into the curriculum, this does not mean that we do not want to change the curriculum to reflect better ways of doing things. How can we integrate technology into the curriculum while changing it for the better?

The Need for a Redefinition of Programming

Bull and Cochran (1991) noted the need for a redefinition of programming as "learner-based tools." The public has a false conception of the term *programming* as something professional programmers do rather than as a set of handles for controlling a computer environment to get the computer to do what you want it to do. Wiburg (1989) suggested the phrase *desktop programming* as an analogy to desktop publishing. This suggests that programming can be fun, easy, and available to all. However, the negative connotations of the term *programming* may be so strong that only such concepts as *learner-based tools* can provide a more useful direction.

What do we want these new tools to look like? What compromises should we make between the cognitive demands required and the need for positive results? Our research suggests that if students are more involved in building the procedures, the products might actually be more creative and attractive. There may be important relationships between process and product.

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Bridging the Gender Gap With LEGO TC Logo

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Numerous studies have indicated that boys score higher than girls on science achievement tests. This is one factor that has led to an imbalance in the numbers of women as opposed to men in upper-level science courses and has discouraged girls from pursuing careers in engineering, physics, earth science, and chemistry (National Research Council, 1982). While no physical, biological, or intellectual reason for this discrepancy has been found, evidence has suggested that cultural biases do play a major role in discouraging women from pursuing careers in the sciences.

Peltz (1990) suggested that perhaps this was due to the fact that "boys have participated in more tinkering activities than girls both at home and at school and have accumulated more positive experiences in areas that include mechanics and electricity." Peltz found that boys have a much more positive attitude towards science and technology than do girls even before 11 years of age. By the time they are in middle school, boys view science as a masculine endeavor while girls see it as a threat to their feminine self-image.

In view of this research, science programs that incorporate hands-on experiences that enhance students' abilities in mechanics and electricity seem particularly essential. LEGO TC Logo may be one avenue that can help encourage girls in these areas.

LEGO TC Logo is a computer software package that combines LEGO building kits with Logo computer programming. Students build models with LEGO pieces and connect them to the computer by way of an interface box. They can then write computer programs to make their projects move, light up, make music, and respond to touch and light sensors. The LEGO TC Logo learning environment allows students to think creatively, solve problems, and pursue higher level thinking skills as they work on their own inventions. Theoretically, it also should provide equal opportunity for boys and girls to become competent and engaged in the process of learning concepts in physics, electricity, and computer programming.

During the 1990-91 school year I participated in a classroom action-research study designed to evaluate the use of Logo as a learning tool. The study was funded by the National Science Foundation and involved nine groups of teachers from around the country who formed collaboratives to study their teaching practices. My group comprised 10 teachers from the Madison, Wisconsin, area. Each member of our group chose a question of personal interest related to the use of Logo in our classroom. I was particularly interested in gender differences in science, so at first I sought to answer the question "Is there a motivational difference in the way boys and girls approach learning with LEGO TC Logo?" Once it became obvious to me that there was indeed a difference, my question focused on finding ways to encourage girls to become actively engaged in Logo learning.

Description of the Population Studied

The study was conducted at a suburban school in south central Wisconsin, with most students coming from middle- to upper-middle-class families where both parents had college educations and held professional jobs. In general, students came from homes where education was highly valued, and many of them were exposed to home computers at an early age. The students studied were in the sixth grade and were 11 to 12 years old.

My LEGO TC Logo group was my homeroom class, a homogeneous group of all ability levels. We studied computer programming for approximately one and one-half hours per week beginning in November. For most of these students, this was their first exposure to programming, so we needed to begin with the basics of what a program was and how it worked. Students were well acquainted with LEGO and with the computer keyboard, so we focused on the Logo language as it was presented in the LEGO TC Logo manual.

Although our school has a computer network, we were unable to use this for our project. Because LEGO TC Logo was not available in a network version, we had to settle for using one stand-alone computer in my classroom. This unfortunately hindered students' ability to test their programs. In the future we hope to use a network version if it becomes available.

The 19 students in my homeroom used the LEGO TC Logo kits during three structured periods per week, each lasting approximately 40 minutes. In addition, they were free to work on their own before school and during supervised study periods. The enthusiasm they demonstrated for their work was delightful. All students seemed to enjoy both building and programming. I didn't have to direct them to get their kits, and they stayed on task for the entire period. At least 2 or 3 students usually went to work on Logo before the start of the school day.

The focus of my research was on whether there was a difference in the way boys and girls approached LEGO TC Logo not only in their level of motivation but also in their willingness to apply newly gained knowledge to unstructured assignments. Specifically, I sought to answer the following question: "How does gender pairing affect a student's approach to LEGO TC Logo?"

I initially collected data to assess if groups segregated by gender did, in fact, show a difference in motivation, task commitment, and overall performance. I used observations, interviews with students, and written surveys to answer the following three questions:

1. Is there a difference in motivation between boys and girls when they build and program with LEGO TC Logo?
2. Are boys more inclined than girls to create projects that diverged from the basic programs supplied in the manual?
3. Are boys more likely than girls to build a project and then conduct experiments to make it perform better?

To answer these questions, I collected data in my class for a period of two months. My students were divided into six groups, three groups of boys and three of girls. All groups had three members except for one group of four. I must say that this is not the ideal situation. I would have preferred groups of two, but limits on the availability of computers and building kits prevented this. I was pleasantly surprised at how well students adjusted to sharing LEGO pieces and working as a team.

From the beginning, I realized that many students were not content with simply following the suggestions in the manual but were much more inclined to experiment by building more complex machines or altering their projects to make them more efficient. Students were all asked to begin by building a car and programming it to move forward a specified number of feet. Then they were challenged to have the car move forward three feet, backward two feet, and then forward again one foot. Later they were asked to build a traffic light that used the flash command and one that performed like a real traffic light. I chose not to limit students to these projects because it was evident that they were very interested in solving problems they invented. Instead, I kept track of what they were working on and I encouraged them to incorporate programming concepts, such as using a subprocedure or a sensor command, into their projects.

After the initial novelty of LEGO-building wore off, it was apparent that most of the boys were interested in building increasingly more complex projects and that most of the girls were rapidly losing interest in the entire project. Only boys chose to work on their projects during unstructured periods, and during LEGO TC Logo class periods the boys actively engaged in learning while the girls needed a lot of directions and reminders to stay on task.

In addition, I looked closely at the types of projects students were choosing and found that the boys were busy creating unique and more complicated inventions while the girls were still working on the beginning projects from the manual. For example, one triad of boys built an alarm system for a house, complete with flashing lights, a siren, and a police car that zoomed to the scene when the alarm sensor was activated. Another team of boys constructed a conveyor belt that dumped garbage outdoors from a house they had built. The girls, on the other hand, were sticking exclusively to the manual. They tended to build the models, then attempt for a brief period of time to program them, and then give up. There was more complaining about lost pieces, greater difficulty with making the programs work, and a general sense of frustration.

I decided at this point to survey the students to confirm my observations that indeed there was a difference between how boys and girls viewed working with LEGO TC Logo. This is a sample of the questionnaire and students' responses based on a population of 19 students—9 girls and 10 boys.

1. *Rate your interest in your LEGO TC Logo project this week.*
   Not interested—4 girls, 0 boys
   O.K.—5 girls, 2 boys
   Very interested—0 girls, 8 boys

2. *Are you working on a project you created or one from the manual?*
   Created by self—3 girls, 5 boys
   Manual—6 girls, 5 boys

3. *When your project was built, did you make changes to improve it?*
   Yes—3 girls, 6 boys
   No—6 girls, 4 boys

4. *How have you felt about working with LEGO TC Logo so far this year?*

   Comments from girls:
   - It is O.K., but I don't like the group I am in.
   - Sometimes it's fun, but other times it's not.
   - It's O.K.
   - It is fun, but it is very confusing and complicated.
   - I don't like it that much, and I think it's boring.
   - I think it is O.K., but sometimes I am not very interested.

   Comments from boys:
   - It's a lot of fun.
   - It has been cool.
   - It's been fun and exciting.
   - I think it is great!
   - I feel that I have gotten a lot out of it, and I want to build everything!
   - I really like it a lot—it's lots of fun.
   - I think it's neat that we get to do this.
   - At first I was excited, and then it was great when we started working on our project.

This survey showed clearly that the boys were very much enjoying their LEGO TC Logo experience and the girls, on the whole, were not. I decided to share these results with my class and ask them why they thought there was such a discrepancy in their reactions. They felt that part of the reason was that boys were more familiar with LEGO building and felt more comfortable making models. In addition, boys were generally more intrigued with cars, motors and gears—a major component of the building sets. One boy commented that he had built several LEGO models before, but the thought of being able to program his vehicle to move was particularly motivating and exciting. The girls, however, were overwhelmed with the complexity of some of the constructions and felt they needed more structure and direct instruction. In addition, they felt much more frustrated when their project fell apart or didn't work quite right. They said they were not used to making adjustments or correcting malfunctions in their projects.

I decided at this point to restructure my groups to mix genders. I hoped this approach would help girls become more familiar with using LEGOs and would encourage the boys to share their expertise with the girls. I encountered absolutely no resistance to this idea. In fact, the suggestion to mix groups was met with enthusiasm from all involved. The girls' interest increased as they met with more success in building and programming.

At first I organized the groups around structured projects that were already started in the classroom. I purposely did this to encourage the programming aspect with LEGO TC Logo. I felt the girls had enough experience with building but had had little success with using the computer to operate what they had built. Several choices were available, including a washing machine, a merry-go-round, a turtle vehicle, an alarm house, and a conveyor belt. Students asked to work on particular projects, and I accommodated their wishes as long as the groups remained mixed in gender. They worked together for several weeks.

I paid particular attention to how the girls were assimilated into their new groups and did all I could to encourage their active participation. For example, I assigned girls the role of keyboarding as the groups wrote their programs. In this way I hoped to capture their interest and familiarize them with the computer language. I also assigned girls the role of spokesperson so that they would be called upon to explain their group's project and reflect on their problem-solving strategies. The boys were still more adept at building the models, but many girls gained more confidence and went on to work independently on building their own vehicles. Two girls in particular were thrilled that their car actually worked, and I witnessed their motivation and task-commitment increase tremendously.

I reassessed the attitudes of the students after three weeks and found a positive change in most girls. Specific results are as follows:

1. *Rate your interest in your LEGO TC Logo project this week.*
   Not interested—3 girls, 1 boy
   O.K.—5 girls, 6 boys
   Very interested—1 girl, 3 boys

2. *Are you working on a project that you created or one from the manual?*
   Student created—5 girls, 7 boys
   From manual—4 girls, 3 boys

3. *When you built your project, did you change it to improve it?*
   Yes—4 girls, 3 boys
   No—2 girls, 4 boys
   Not built yet—5 students
   No Answer—1 student

4. *How have you felt about working with LEGO TC Logo so far this year?*

   Comments from girls:
   - I think it's O.K. I learned a lot. I like it more than when we started.
   - At the beginning I didn't like it at all, but now it's more fun and we can do

more things.

- I felt it's better switching groups around.
- I don't really like it!
- I just can't seem to get interested. For some reason I have never liked LEGOs, even when I was little.
- I kind of like it after we changed groups with a couple of boys in our group because they really knew what to do. The ones in my group explained things and let us work on the computer and program, too.
- The longer we were in LEGO TC Logo the more I liked it. At the beginning I thought it was stupid, but now I like it. If I wouldn't have been encouraged to try I don't think I would have even tried LEGO TC Logo, but I'm glad I did.
- When I was in a group I didn't like it that much. At the very end I sort of went off by myself and worked on my own project. I like it a lot more.
- I am very sorry to see LEGO TC Logo end. I think it was a very rewarding program. I also enjoyed having a boy in my group because he knew some things I didn't.

Comments from boys:

- I enjoy it but I liked working on my old project, the alarm house, better.
- I like it better now because people do not have the same kits and it's easier to get pieces. I like it a lot.
- Pretty good.
- It's O.K.
- I have felt very good about working on LEGO-Logo.
- Interested.
- I have felt that we haven't had enough time until now.
- It's been a lot of fun.

After reviewing the survey, I felt fairly certain that my decision to restructure the groups was a positive move for the girls. What was somewhat alarming, however, was the drop in interest among some of the boys. I was fairly confident that this was not due to the mixed-gender grouping but rather to my restrictions on the kinds of projects they could complete and the programming that I was expecting. My observations indicated a much higher interest level from the boys than the survey indicated.

I decided to confirm my belief that mixed-gender grouping was desirable for all students by trying this type of approach from the start with another sixth-grade homeroom. After two weeks, I used the same survey and found a very high interest rate among both boys and girls. What was even more encouraging was that all of the girls in this homeroom reported that they had made changes to their project to improve it and 70% of the girls created an original project. Most boys in this homeroom rated themselves as very interested in LEGO TC Logo, and my observations confirmed a very productive and positive working relationship between all group members.

Conclusions

The results of my classroom action research raise several issues regarding gender differences in the use of LEGO TC Logo with middle school students. First, teachers must recognize that there will likely be a difference between the skill level, motivation, and willingness to complete creative problem-solving projects when girls are initially exposed to LEGO TC Logo. This finding has been confirmed both in my study and in another three-year study by Faulkner and Anderson (1991). The likelihood that this will occur seems to increase as students become older. This directly correlates with numerous studies that have found gender differences in science lab classes and is particularly distressing given the ratio of boys to girls in careers that involve mechanical skills, such as engineering and physics. Girls may need more direct instruction with building and with programming, and it may take them longer than boys to feel comfortable enough to create independent projects. Given additional opportunities to explore LEGO TC Logo, however, most girls will gain confidence and increase their motivation.

Teachers may want to use mixed-gender grouping when using LEGO TC Logo. When I have taught LEGO TC Logo in other sixth-grade classrooms, the mixed-gender groupings have worked successfully. Cooperative learning strategies that group students of varying abilities may also be advantageous. Girls in my classroom responded very well to the encouragement from boys and seemed to share in their enthusiasm after they became more comfortable with the materials. Assigning girls to leadership roles in the group and having them actively involved at the keyboard when any programming is done helps a great deal.

Another issue that educators must address is that of motivating girls to self-select when offered opportunities to use materials or take courses in the physical sciences. When I offered a LEGO TC Logo workshop to middle school students in another school district, 13 boys and no girls registered. Many girls report that they never really liked to build with LEGOs. The gender differences seem to emerge when students reach the intermediate grades in elementary school. It is important, therefore, to try to interest girls in the primary grades in building and construction projects. Some of our work other work indicates that with adult supervision, children can successfully use LEGO TC Logo as early as the second or third grade. Third graders at my school incorporated the simple machine curriculum into their science unit on forces and work. Their teachers reported that students of both genders were enthusiastic and equally engaged in the building process.

Several approaches can be taken to try to appeal to girls' interest. One is to redesign the building kits to incorporate more feminine themes; rather than machines, pirates, cars, and battleships, the kits might include amusement parks, fantasy lands, schools, or fairyland castles. Bricks could be changed from primary colors to pastels. The scientific concepts needed to operate the various rides and programming opportunities could still be challenging but might target a female audience. The traditional themes would still be available for students who preferred to use them.

If companies are not willing to alter their products, it will be up to the classroom teacher to offer projects that engage girls as well as boys. Students might design a creative art sculpture, construct a fantasy town, build a carrousel, or invent a royal carriage. These projects could be easily incorporated into the existing curriculum. LEGO TC Logo might also be integrated into a broader social science theme and used as a part of a display or project.

Educators must also rethink how Logo programming can fit into the parameters of a typical school curriculum. Teachers often are too rigid in their beliefs that all learning must take place within the confines of a particular subject category or that teachers must take the role of information-giver rather than problem-solving facilitator. The knowledge gained from using LEGO TC Logo is not really specific to any one particular subject area, but rather permeates all curricular areas. It teaches problem-solving and cooperation and encourages innovation. Teachers must feel comfortable with allowing students to invent their own projects and be ready to assist them in looking for solutions to their problems rather than worrying about whether students have attained a certain level of programming or building proficiency.

LEGO TC Logo allows students to focus on process rather than on product. It gives them freedom to design and redesign, to make mistakes in a nonthreatening environment where creativity and innovation are encouraged rather than discouraged. This type of learning atmosphere may be particularly advantageous to girls who may feel less adept and knowledgeable than their male classmates. Given the flexibility to explore, set goals, solve problems, and learn experientially, girls will gain confidence along with expertise.

Science educators are reassessing what skills are essential in the highly technological society of the future and are shifting the focus of education from memorization of facts to an emphasis on critical thinking, scientific design, and problem-solving. Andrew Molnar of the National Science Foundation has said that "Education must shift away from learning to cognition. We must teach students how to think. We are on the threshold of a dramatic change in science, and students must learn to grasp, understand, and apply." With the apparent shift toward introducing more technology into the classroom, the outlook for improving student motivation and achievement is very encouraging. The education of teachers about gender differences that may occur with the use of these types of instructional materials is critical if girls are to achieve their full potential. Hopefully, the introduction of hands-on experiences in mechanics, electricity, and computer science in the early grades will help encourage girls to continue their education in the physical sciences and make them feel that they are equally as competent as their male counterparts.

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Increasing Cooperative Behaviors in an Urban Middle School Classroom

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This article reports on my investigation into collaboration among the students in one of my sixth-grade Logo computer programming classes. I tried to learn how collaboration operated in my room and how the students thought about it.

I work in a middle school in Boston in which there are 340 students in grades 6, 7, and 8. The school is located in an inner-city neighborhood that has recently experienced a sustained outburst of juvenile violence. The interaction among students is characterized by verbal hostility, insults, and putdowns. This constant verbal confrontation and aggression frequently erupts into fistfights. The prevailing attitude toward adults is anti-authoritarian.

My classroom contains 15 Apple IIe color computers and three printers. I usually teach seven different groups of students per week. Some of the classes contain about 25 students and some only half that number. The sixth-grade class on which I focused my research included 25 students so that 2 students usually were working together on each computer. Other characteristics of the group were that approximately one-third of the group were special-needs students, and there was almost a balance of boys and girls. I worked with each group of students three times per week. I used *LogoWriter* for the first time with my research class. I had previously used *Terrapin Logo.*

Teaching Goals

In my Logo classes I have two types of goals—academic and process. My overall academic (content) goal is to have the children obtain a reasonable degree of mastery of the Logo programming language.

For this research project, my specific academic goals were:

- to expose the students to the mechanics of *LogoWriter*. I wanted them to learn how to use the command center, flip the page to record procedures, move the cursor from the command center to either the edit screen or the drawing screen, stop a procedure, change colors, clear the screen, and save work.
- to review and (for students with no background in Logo) to teach the fundamental Logo drawing commands FD, BK, ST, HT, PU, PD, and REPEAT
- to get every student working with procedures as an automatic step in creating pictures on the drawing screen
- to acquaint students with features of *LogoWriter* that are not available in other versions of Logo, such as: using multiple turtles, simple animation, changing the turtle shape, editing the turtle shape, creating new turtle shapes, typing on the

graphic screen, and using the LABEL, STAMP, and SHADE commands

- to extend the students' knowledge of Logo commands to include SETH, SHOW HEADING, PRINTSCREEN, PRINTTEXT, and NAMEPAGE
- to extend the students' mastery of *LogoWriter* mechanics, including using the editing keys, cutting, copying, pasting, marking, using turtle move, and using the Help keys

I divide process goals into two categories: social and intellectual. The social goals I sought to achieve include the following:

- to have the students speak to each other in a nonabusive way. This objective included tone of voice as well as choice of words.
- to have the students remain seated most of the time. This goal was somewhat in conflict with my other goal of encouraging students to share ideas.
- to have students who were paired at a computer work together rather than have one person do everything while the other person sat by socializing, complaining, or arguing.
- to have students spend at least 90% of their time on task in the computer class

I also hoped to achieve the following intellectual goals:

- to give students a sense of intellectual empowerment and excitement about creating pictures with Logo
- to get students to use each other as resources when they had a problem or wanted help rather than using the teacher as the only resource
- to help students develop a sense of the debugging process so that if a procedure was not working the student could discover why and change it. This emphasis meant learning not to rely only on an adult to fix the problem.

Research Focus

I became interested in the ways students in my class learned from each other and supported each other in their learning. I was concerned about the classroom climate in this particular Logo class. I was disturbed by the students' lack of coping skills, which prevented them from dealing with their frustration. I was troubled about what I viewed as their excessive dependence on my assistance when they encountered difficulties or frustration in working on problems. I was concerned by some of the students' difficulties in working in pairs at the computer for example, domination by one student while the other student disengaged, often becoming disruptive in the process. By learning methods to support collaboration, I felt I could address some pressing issues in my Logo classes. My original intention had been to study the way changes in the classroom environment promoted student cooperation and independent learning/work habits.

Background Reading

To gain perspective onthis issue, I read resources such as Johnson, Johnson, and Holubec's (1988) *Cooperation in the Classroom;* Turkle's (1984) *The Second Self: Computers and the Human Spirit;* and David Hopkins' (1989) *A Teacher's Guide to Classroom Research.*

Teaching Interventions

I wanted to increase cooperative behaviors (academic and otherwise) in my classroom. To accomplish this, I tried to make the classroom environment more supportive of collaborative work by my students. I implemented several strategies to achieve this goal:

- I had a discussion with the students about ways they could support and treat each other in a positive way.
- I posted a list of desired cooperative behaviors that I expected them to use in the classroom.
- I gave them a list of cooperative behaviors and asked them to evaluate themselves on how well they had used them in the Logo class.
- I asked them to demonstrate and share the way they had solved a problem with the whole class as part of the routine.

As I became more familiar and comfortable with *LogoWriter*, I began to understand and explore with the class certain empowering features of this version of the Logo language. The students were able to create things on the screen that were very exciting and that gave them a sense of great accomplishment. Their activities included editing the turtle shape, using the STAMP command, using the SHADE command, and writing some simple animation routines. Because these features also were new to me, students had to work with them without depending on me for assistance.

Managing Research

To investigate the effect that these various strategies were having, I collected several types of data. I took pictures, kept a journal of my daily observations, ensured that a complete record of all student work was kept on disks, and interviewed students about the ways they had learned from other students and the ways in which they had helped other students. I attempted to videotape the class, but this was not successful because it was too distracting to individuals. I also collected the students' own notebooks in which they recorded notes about procedures. I compiled a chart that compared students' overall school conduct (as assessed by the homeroom teacher), their Logo cooperative behavior level (assessed by me), and their Logo-language knowledge.

Difficulties

Factors that I had not anticipated in my plan, such as the enthusiasm and empowerment generated by changing and creating turtle shapes, became factors in changing the classroom climate. These developments struck me as an example of real life getting in the way of the laboratory model of a classroom.

As I studied the data—students' procedures and pictures, student interviews, notebooks, and classroom pictures—I became more interested in studying the way students were helping and supporting each others' work rather than in studying the factors that may have caused this to happen. My focus changed from zeroing in on the causes of the behavior to zeroing in on the behavior itself. I felt on much more solid ground when carefully studying the evidence that students were learning from each other and were supporting each others' work. By careful study, I was able to glean some ideas about supporting students in that aspect of their learning. At the same time, I had a record of my efforts to move them along in that direction. Which of my teacher behaviors (if any) contributed to the peer teaching/learning is still somewhat unclear to me.

The greatest problem I encountered was making accurate observations during class time. I found it very difficult to step back and observe while managing a very challenging classroom setting. The only method I found to deal with this was to jot down notes after the class was over.

I found that as students became more engrossed and competent in their work with Logo, it was difficult to sustain the emphasis on recording their work on paper. Procedures saved on disk became the mainstay. Recording the dates of the work on the student's disk was more problematic. Because students merely press ESC to save current workspace, the title did not indicate the date on which work was done. (This is an example of a practical difficulty caused by being a *LogoWriter* rookie.) This difficulty is easily surmounted by teaching students to rename the page with each new class, but at the time of this research I was so overwhelmed by new features of *LogoWriter* that such a simple solution did not occur to me.

An interesting difficulty I encountered was related to my morale. On days when I was discouraged by the way the class had gone, I found it difficult to force myself to be as complete in my data gathering. This problem is analogous to the very deficit I was trying to address in my students: difficulty in coping with frustration. This area is one where I believe the concept of *teacher as researcher* can play an important and constructive role. Over the course of this year, I felt that researching what was happening in my classroom helped me learn to become detached from it. Rather than being overcome by a sense of failure, I have become more focused on trying to describe what has happened. This is an attitude I tried to instill in my students vis-á-vis the debugging process. Rather than letting them become dismayed when a procedure didn't do what they wanted, I tried to get them to concentrate on figuring out why it didn't work.

What I Learned

I gained two kinds of learning from this project. One type of learning relates to what I learned about the process of research. The second type relates to what I learned about my students and how they were able to help each other and view this helping activity.

Student Work

I gathered data on how students shared ideas by looking at printouts of student procedures, examining the printouts in reference to the seating plan, keeping a log of my interventions, and observing student behavior.

A dramatic illustration of student-based learning is provided by the work of one of my students, Nelson. By observing Nelson, I realized that he had a strong trial-and-error approach to learning. He constantly proposed different hypotheses, tested them, and drew conclusions. A clear example of this was his exploration of the keyboard. He held down the Apple key with every key to see what happened. He was able to teach me about using Apple–Up arrow and Apple–Down arrow to move around in the procedure library. He also used this trial-and-error technique to discover the *LogoWriter* Help and turtle move functions. He was the exclusive source of information about Apple–arrow, turtle move, and Help features. I never taught these to anyone, and no one had ever used them prior to Nelson's discovery of their functions. By year's end, I had observed about one-third of the students using them.

There is a second example involving Nelson. I did not directly teach him the capability of PRINTSCREEN; but when as a newcomer to *LogoWriter* I first started using it, he saw me and immediately incorporated it into his procedures. He then became the printer expert. His work station was initially near the printer, but he finagled the student sitting at the computer even nearer to the printer to trade seats with him in return for his assistance when that student needed to print something. Thereafter, all the printing and information about how to do printing was handled through Nelson.

In this respect, Nelson provides an example of the way a student's expertise can offset social difficulties that student encounters when expertise is not a factor. Observing him closely through the year, I found Nelson to take offense easily, to be rigid in his thinking, and to be extremely intense and persistent. These qualities make for a somewhat abrasive interpersonal style. He frequently ran amuck of the established authority in the school because he was so quick to jump to conclusions and so unyielding in his convictions. In spite of this prickly style, I observed him functioning very smoothly as the class printing manager. Students sought him out and readily accepted his edicts when it came to printing.

Another of my students, Abigail, showed me other important things about student-based learning. Her personality was such that my teacher interventions to get her to use procedures were at best ineffectual and at worst counterproductive. She would never begin writing the procedure until she had the picture exactly the way she wanted it from direct mode. In spite of meticulous note taking, she never copied the commands accurately; therefore, in her view, the material in her procedure notebook never worked. She would then give up in disgust. I was never successful in persuading her to attempt to debug. She would have nothing to do with a deviant procedure a day after she wrote it. She had lost the train of thought that had generated it and found her notes inadequate to regenerate it perfectly (the only acceptable outcome to her).

Abigail's computer neighbor, Tanya, became quite intrigued with making procedures that used SETSH to change turtle shapes and STAMP to place them on the screen to create a scene. The title she gave the procedure was LANDSCAPE. Abigail, whose confidence was steadily ebbing, to judge from her increasing negativity and resistance to my suggestions, noticed the idea. Abigail attempted to replicate Tanya's procedure directly by copying it into the editor (flip side). This was the first time I had ever seen Abigail work on the flip side without having first done everything in direct mode. As I watched, I noticed that although she began by attempting to replicate Tanya's work exactly, she began to add her own modifications. I strongly suspect that this began because she copied Tanya's work inaccurately. Each time I came by, Abigail was trying out a slight variation of the basic LANDSCAPE procedure.

My interpretation is that this surreptitious assimilation of Tanya's idea allowed Abigail to get off the hook in her own eyes: She was saved from her ignominious failures to produce procedures that worked. In copying the content of the procedure, she inadvertently adopted the medium, namely, the idea of using a procedure. For the first time, Abigail became a real user and inventor of procedures. It was necessary for her to do this in her own way and on her own terms. I had been trying to mold her into a "let's try it and find out what happens" model, which simply did not suit her temperament. It was far too risky for her because success was not clearly defined and thus (in her view) not attainable. Using Tanya's work as a model and accidentally making modifications gave her an illusion of control that was necessary for her to gain confidence. The STAMP primitive was an ideal tool for Abigail to use in her procedures because it produces relatively sophisticated results without requiring sophisticated programming. This technique allowed Abigail to meet her own exacting standards. Abigail was able to get from Tanya what she would probably have never gotten from me, because I was not offering a message that was compatible with her temperament or needs at that time. My conclusion is that a learning environment that encourages students to collaborate can compensate for instances where teacher interventions may not have been optimal.

In both Nelson's and Abigail's cases I found myself clashing with their rigidity when I made a suggestion that would invariably be rejected (if not resented). I felt myself getting hooked into a power struggle and/or a personality clash. By backing off and letting either their own (in Nelson's case) or another student's (in Abigail's case) ideas fill the vacuum, they made much more progress; and I was still available to help in other areas in the class.

Several themes emerged from my comparisons of my students' work:

- Ideas were being passed on from student to student.
- Seating proximity in the room affects the combination of ideas a student gathers from his/her peers.
- Student personality/thinking style needs to be taken into account when a teacher offers suggestions or interventions.
- Other students may be able to offer ideas in a more effective way than a teacher can offer them because of personality or learning-style issues.

- Students who are viewed as experts attain a status that can offset negative social standing in certain situations.

Student Interviews

After I had observed and collected some evidence about the ways students shared ideas, I wanted to learn what their thoughts and ideas about sharing and collaborating were, and how they meshed with what I had observed from their work and behavior. I conducted interviews at the end of the school year, as our year's work was drawing to a close.

The following examples of Tanya and Abigail's work illustrate the relationship of their ideas and the forms their ideas took. Their procedures and projects were not based on any of my specific suggestions, although I had taught them to edit turtle shapes, to change turtle shapes, and to use STAMP and SHADE. In one interview question, I compared my own perceptions about the connections between the two students' work with Abigail's description of her collaboration:

Q. Abigail, have you ever seen something on the screen that helped you or gave you an idea?

A. No, I mostly make my own, like the Store procedure. It's too long for one thing.

In fact, Tanya had originated the style of two of Abigail's procedures, GRASS and LANDSCAPE. The overall design, look, and feel of these two procedures were identical to Tanya's, except that there was considerable innovation by Abigail in the details of one of the procedures.

The students who were interviewed were chosen at random, without regard to my assessment of any strength or weakness in the area of cooperative learning. I was struck by the fact that all except one of the students I interviewed made statements that were positive about helping and being helped in the computer class. This showed me that students had by the end of the year begun to experience positive attitudes about cooperative learning and mutual support. I was intrigued by the fact that students were more likely to remember helping someone than being helped. In several instances, I persisted in asking probing questions about certain interactions I had noticed and was thus able to elicit a memory about learning from another student.

This finding sheds some interesting light on the value of the research process itself. Had I not been in the process of researching ways students had of helping each other, I may not have made the observations I did, or examined student procedures to see how one student used another student's ideas and experiments. The knowledge I gained from the observations and the procedures enabled me to elicit more information in the form of interviews because, under superficial questioning, students often did not give the same answers that they gave when asked more specific, pointed questions. Thus, my previous research not only made my interviews more useful, but it also made the interviews a learning experience for the student. The interviews may well have helped students become aware of something that they might not have become aware of on their own. A clear finding from my interviews is that it can be misleading to take at face value students' statements about where they got help.

It would be interesting to learn more about the students' attitude that helping is more valuable than receiving help. It would be interesting to know if this attitude is widespread and to explore whether it has broader implications. More work could be done with this student group to build a culture of cooperation where they perceive seeking and giving assistance as valued and nonthreatening activities. I have a strong sense from the interviews that helping is a desired role. I am not certain that there is enough evidence to definitively conclude that being helped is stigmatized. Such a bias against being the one helped is consistent with what I observed among many members of the group as an excessively defensive attitude about their own competence. Verbal clashes between the children arose from a pattern of putting each other down and overreactions to putdowns. This was particularly evident when students were working as partners in solving a Logo problem. When a bug was found in a procedure, comments such as "Stupid...I told you not to do that" or "Oh shut up, you're stupid" were typical reactions that repeatedly occurred.

Students' ideas about helping can be quite complex and at apparent odds with observed behavior. This was most striking in Billy's case. He placed a very strong emphasis on the value of working together. He saw it as a way to broaden his resources and minimize his liabilities. "I do something wrong and he fixes it," he said. Billy's partner, Tony, also viewed helping as a positive thing that "takes the pressure off." Both students saw being helped by other students as a resource rather than a stigma. Billy also had a very pragmatic view of how to resolve conflicts in ideas: Both ideas should be tested and the one that worked should be used. He seemed invested in outcome rather than in ownership of an idea or in a power struggle. I would characterize his views as mature in the sense that I share Billy's belief that outcome is important, and I feel that his way of resolving conflict is effective. It was a surprise to me that Billy had these ideas because I would have described him as one of the least mature people in the group prior to interviewing him. I based my previous judgment on many of his young physical behaviors, such as making silly noises and kicking and grabbing at people. His positive behaviors were more subtle and were often masked by his playing around.

My interview with Nelson provided a different example how a student's reality can be at odds with observed behavior. Nelson was quite sophisticated in explaining his ideas about helping people: "I like to teach, to try to figure out, to encourage.... If I'm helping, I don't do everything. I just show them how." However, observations of his helping behavior indicated that he lacked respect for the agenda of those he helped. He frequently took over another student's work by reaching over and typing in what he had decided should be typed in next. He got fixated on a certain aspect of the problem and truly did not understand that the other person might not care about the same thing he cared about. If things were not done his way, he got very angry and resentful.

Another theme coming out of my interviews is that students who lack status can be effective helpers and can gain acceptance through their expertise. Michael is a striking example of this phenomenon. He takes medication for attention-deficit problems and is in special-needs classes. Michael had worked with *LogoWriter* in two previous schools. He was already comfortable with editing turtle shapes and enjoyed showing other students how to do this. In spite of his low formal academic ranking, Michael demonstrated consistent willingness to explore Logo problems. He was able to work successfully on procedures and problems given to the class. When written material was above his independent reading level, he was able to compensate. All these factors resulted in Michael writing many procedures and helping students who sat near him with their procedures. In his interview, Michael revealed that he takes considerable pride in his ability to help other kids with computer work and that this is an important activity for his self-esteem. It was very surprising to me that Michael was not an object of ridicule and that students accorded him a grudging respect.

Conclusions

One of the surprises of my research experience was the discovery that investigating and teaching can be related in subtle ways. This overlap was particularly apparent in the interview experience, where my questioning the students about ways in which they had received help from peers was actually a way of increasing their perception and awareness of what they received from classmates.

A second revelation was the importance of specific observations for teaching me concepts that I could generalize to my overall teaching style. In analyzing the section on Abigail's work and describing how she was able to get more help in learning to write procedures from emulating her neighbor Tanya than from the kinds of teacher interventions I was using to get her comfortable with using procedures, I saw many things that I had been unaware of at the time. I saw how incompatible my statements, "Why don't you try," and "Let's see what happens" were with her temperament. I saw how hard she was on herself, how difficult it was for her to be proud of what she had done, and how important it was to her to produce something that was perfect. My interventions had not energetically addressed those powerful influences on her learning. The lesson for me in this experience was to respect personality type and to be more sensitive to students who have Abigail's general style. Strategies of pairing them with more innovative students whose work they can emulate may facilitate successful and comfortable experiences for such students. Without having made detailed observations of Abigail and without assessing the meaning of what I saw, I would have missed this valuable lesson.

By year's end, the Logo class I had studied had changed in many ways. The students had all become more independent, outspoken, and, above all else, interested in their peers. Every day they seemed more like the teenagers they were rapidly becoming. We had all grown tremendously in our knowledge of and comfort with the world of *LogoWriter*. Students were exploring their own projects and procedures with great energy. Teacher-directed projects were available for those who needed help in choosing a direction, but the skills they had learned—the ability to turn the turtle shape into a car or a helicopter and make it move across the screen, work with multiple turtles, and stamp shapes—created so many fun activities that it was rare for me to have to force a student to become engaged in working with *LogoWriter*. As students became more knowledgeable, their interactions changed. They were likely to show each other a new skill (for example, using turtle move or the Help key) or to show off a new procedure. The noise and confusion never really abated, but the nature of it decidedly shifted in a more constructive direction. (The verbal putdowns and bickering did not diminish nearly to the extent that I would have liked, and I have come to realize that I must constantly intervene and insist on standards of what I have come to call "friendly talk.") The causes of the changes I observed in my classroom are multiple: some were developmental, some were a function of momentum gained in learning the subject matter, and some were from the teacher interventions I introduced to the setting.

What are the implications of what I discovered through my interviews? It appears that helping is more valued than being helped. Ideas about helping do not always match observed behavior, and effective helping can offset certain status liabilities within the group.

Clearly, there are no simple answers. I would like to do more research to determine if being helped is commonly viewed more negatively than helping. If this turns out to be the case, I would like to place more emphasis in my class on the value of asking for help, and to try to find ways to support students seeking help. The implication that effective helping can offset status liabilities certainly supports the notion that cooperative learning is an important addition to the school climate (particularly at the middle school level). Children in early adolescence are known for their cliquish and exclusionary social practices, which can often lead to very mean and hurtful incidents. In my school, where violence permeates the surrounding community, this developmental trait can erupt into physical violence as well. It is important to realize that supporting cooperative learning behavior, identifying students who are at risk for being excluded or picked on, recognizing their strengths, and helping them share their knowledge with peers can be a significant strategy for countering such victimization.

The notion that students' ideas about helping are at odds with observed behavior is quite complex. It seems likely to me that ideas drive behavior, so it is encouraging to hear students express appropriate views about helping. That the behavior has not yet caught up is not all that surprising, particularly given the threatening social climate that these students are living in. To me this finding underscores the idea that students need support and conscious instruction in this area of their learning. They need to be taught, step-by-step, how to go about what we adults often loosely describe to them as "getting along." Indeed, given the hazards of the world my students enter after they walk out of school each afternoon, a convincing argument can be made that such skills will serve them at least as well as the traditional academic skills we spend so much time and effort on.

I have often heard it said that research opens up more questions than it answers. That conclusion has certainly been my experience. As I look back on the Logo Action Research Collaborative project as a whole, I remember Molly Watt challenging/probing my statements with, "How do you know that?" Going through this experience has changed the way I look at my classroom. I constantly ask myself, "How do I know that?" This often leads to other questions, such as "Do I know that or am I assuming it?," "What does this mean?," or "Why is this happening?" By posing these questions, and starting to seek the answers, I have found a powerful source of growth in my teaching. This force has been amplified by meeting with other teachers engaged in the same process to share and evaluate our experiences.

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A Magnifying Glass Has Two Sides: Observing the Effects of Collaborating on Two Research Collaborators

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Abstract

Research on the impact of Logo has tended to focus first on the students, and then later on classroom teachers. The methodology has expanded from an examination of student learning to include considerations related to the classroom teacher. At the same time, the role of researcher has often shifted from that of an objective observer to that of a participant-observer. Rarely, however, has the individual teacher being observed had a truly reciprocal role, with equal attention being accorded to the views of the teacher about the activities and interpretations of the researcher. In this ongoing research project, the idea of reversibility, essential in mathematics, Logo, and Piagetian epistemology, is extended to the research paradigm itself.

Introduction

This project has had many beginnings, and will continue to have many endings. Some of the beginnings involve the University of Lethbridge, others involve Eastridge Elementary School, and at various points their two paths join, then split again, then rejoin and so on. As part of his B.Ed. program at the university, one of the present authors, Warren Toth, took a computers in education course, which emphasized Logo, from the other author, Dr. J. Dale Burnett. A couple of years later, Dale was visiting Eastridge Elementary School and bumped into Warren. A quick visit to Warren's classroom convinced him that this was a special classroom in a special school. The school is organized along different principles than most elementary schools in Alberta, in that there is an opportunity for teachers to teach their subject specialty, much like in junior and senior high schools. The school building is relatively new, and the principal is notably enthusiastic about his school, his teachers, and his students. In Dale's eyes this looked like a good place to spend some time. This report represents the first of what is hoped will be a series of reports on computer-related activities at Eastridge Elementary School. The school is located in the small rural town of Cardston in south-western Alberta.

A brief word on the nature of the study is in order. The underlying assumption is that whenever a researcher from the university visits a school, there are many effects. Some are intended and noticed; others are noticed but not reported because they lie outside the bounds of the study; and still others may not be noticed at all because of the mindsets of the people involved. This project is a deliberate attempt to examine and document the effects of a research study from two viewpoints: that of the researcher and that of the classroom teacher. However, the two viewpoints are not intended to be independent. The project is a cooperative one from the outset. Regular discussions are a feature throughout. Both parties are primarily interested in what the students are learning. Yet, while working together, each party is likely to benefit from the other's background and perspective. Future reports will include a detailed analysis of student work and their responses to a detailed questionnaire.

This article is intended to emphasize the teacher's voice. It addresses the question, "What was the impact on the teacher of being involved in this research project?"

Context is important for understanding. While this principle is recognized by reading specialists, it is just beginning to be assimilated by educational researchers. Thus, the preceding paragraphs are intended to help the reader appreciate how the present research project originated. Much of the next section is intended to help illuminate the genesis of Logo activities at Eastridge Elementary School.

Logo at Eastridge

During the 1986-87 school year, Eastridge Elementary School offered a regular "gifted" program to about 5% of the school population. Students who were part of this enrichment program were selected on the basis of their past achievement on the Canadian Tests of Basic Skills (CTBS), I.Q. tests, and creative-thinking assessments. However, several problems arose. Even though several instruments were used to determine eligibility, the staff felt unsure that they had identified all those who were truly gifted. Some parents claimed their child was gifted, and disputed the screening process when their child was not included in the gifted program. Social problems also arose, and in many cases the gifted students became over-confident. Many of the "normal" students also rejected those in the gifted class because of feelings of exclusion or jealousy. Additionally, students who met the criterion for this program were almost entirely non-native, even though one third of the student population was native.

At the same time, the school initiated a 10-week computer literacy course for all students in grades four, five, and six. All 12 of the computers from classrooms throughout the school were pulled together to make a temporary lab in the library. The overall objective was to acquaint students with computers in an enjoyable and meaningful way so that they would feel confident in using computers independently. Not only was this objective met, but the staff also found that computers (when combined with quality software such as Logo) provided an extremely powerful learning environment that encouraged creative thinking, problem solving, and the development of higher level thinking skills. The computer class also offered a less traditional, more student-directed, discovery-based approach to learning. In Warren's words,

> When we looked at this class, we couldn't help but notice how similar this learning environment was to the one we were trying to provide in our gifted program. The only difference between these two programs was the fact that the

one included all students, while the other only included 5% of our total student population. Seeing this we thought, "Why not eliminate a lot of the problems we were experiencing with gifted education by providing a gifted education class to all students through the use of the computer?" With some creativity and a lot of hard work, our principal was able to come up with a schedule where we were able to provide an "enrichment" class to *all* students in grades four, five, and six for 50 minutes twice a week, and still keep all the other classes that were previously offered. Even though it was a lot of work to get this program into place, we felt as a staff that because of the potential the program had to help kids, it was well worth the effort.

In the fall of 1987 we established a full-time computer lab and an enrichment class where gifted education was provided for all students. The overall goal of this class was to do just what its name implies—enrich the educational experience of all students so that everyone could develop to his or her full potential. The time was split fairly evenly among keyboarding, word processing, and *LogoWriter*. The rationale behind having such a strong *LogoWriter* component was not to make computer programmers of our students, but rather to provide the experiences and knowledge students can gain in the process of working and playing with *LogoWriter*. Our vision of what could be done with *LogoWriter* can be best stated in the words of Dr. Seymour Papert (1980): "In my vision, the child programs the computer and in doing so, both acquires a sense of mastery over a piece of the most modern and powerful technology and establishes an intimate contact with some of the deepest ideas from science, from mathematics, and from the art of intellectual model building."

As these concepts and skills were taught and evaluated, students were provided access to computers in the morning during their math and language arts time. This provided an opportunity for them to apply the concepts and skills they acquired in the enrichment class and to do any or all of the following:

- complete assignments or reports in all subject areas with increased quality and in unique and creative ways
- develop their language arts abilities by creating, editing, illustrating, publishing, and even animating their own stories, poems, and other written work
- develop their math abilities by exploring and experimenting with concepts associated with geometry, measurement, problem-solving, graphing, recursion, and even some concepts in trigonometry and algebra
- explore and learn new concepts in a way that suits their own learning styles and allows them to progress at their own rate

The approach used specifically in teaching *LogoWriter* was as follows:

Grade 4: Exploring and playing with basic Logo concepts and commands, turtle drawings, turtle geometry, and simple procedures.

Grade 5: Greater emphasis on experimentation with concepts and commands in higher level projects and activity cards.

Grade 6: Emphasis on using skills and knowledge gained in past classes to create unique projects involving more than one turtle at a time and using text, sound, and multiple pages to get the desired results. This becomes a more open-ended, student-directed approach that is a lot of fun for the students.

Evaluation of students for this course was done on an individual basis. Emphasis was placed on personal growth acquired in the process of accomplishing individual projects. Individual projects were also evaluated for creativity, understanding of technical concepts, difficulty, quantity, and quality of work. Measurement devices included written tests, hands-on tests, computer-generated tests, samples of student work, and teacher observation.

Given this background to the structure of the enrichment class, what did the students actually do? And what did they think of what they did? Here is an illustrative example of one sixth-grade project, described by the students who completed it:

> Our project has a whale, a boat, and a person. It starts with the whale surfacing and then it stops. The person says, "Oh, no, it's a sea monster," and then he says, "Swim for your lives." The person jumps overboard and swims away from the boat. The whale goes under the boat, surfaces, and swallows the person.

The actual *LogoWriter* procedures developed by the two sixth-grade students were:

```
TO   SETUP
TELL  0    PU    SETPOS  [80   -80]     SETSH  7    ST
TELL  1    PU    SETPOS  [100   -80]    SETSH  4    ST
TELL  2    PU    SETPOS  [120   -80]    SETSH  1    ST
TELL  3    PU    SETPOS  [-60   -35]    SETSH  8    ST
TELL  3    PD    STAMP     PU    HT
END
```

```
TO   SETUPSAILER
TELL  3     PU
SETPOS  [-69  -30]
SETSH  16     ST
END
```

```
TO   PLAY
SETUP
TELL  [0  1  2]
SETH  290
REPEAT  100 [FD  1]
PR  [OH NO IT'S A SEA MONSTER!]
WAIT  30     CT
PR  [HE'S GOING TO EAT US ALIVE!]
WAIT  30     CT
PR  [SWIM FOR YOUR LIVES!]    WAIT  20     CT
SETUPSAILER    WAIT  10
TELL  3    SETSH  17     SETPOS  [-75  -30]
WAIT  10    TELL  3    SETSH  18    SETPOS  [-80  -40]
    TELL  3     SETSH  10
WAIT  6    SETPOS  [-80  -42]    TELL  3
    SETSH  19    SETPOS  [-80  -43]
TELL  3    SETH  270
REPEAT  27 [FD  1]
TELL  3    SETSH  2
TELL  [0  1  2]    SETH  220
REPEAT  37 [FD  1]
SETH  272
SETH  300
REPEAT  27 [FD  1]
TELL  0    SETSH  9
REPEAT  10 [FD  1]
SETH  300
TELL  0    SETSH 7
END
```

The structural logic of the main procedure and its subprocedures may be represented by the block diagram in Figure 1.

Ideas implicit in the student-constructed procedures include:

- using SETPOS to locate shapes (coordinate geometry)
- using three turtles to make one large shape (the whale)
- using PR to print text on the screen
- using one turtle to take the role of two different shapes (the ship and then the sailor) by using STAMP
- using SETH to specify the direction of movement
- using REPEAT to provide animation

Items from a questionnaire given at the end of the course and the responses of the two students who developed the project included the following:

Did your project turn out the same as you had planned at the start of the unit?
Both: No. There was a sea monster and it was going to eat a ship, but instead a man jumped off the boat and the monster ate the man.

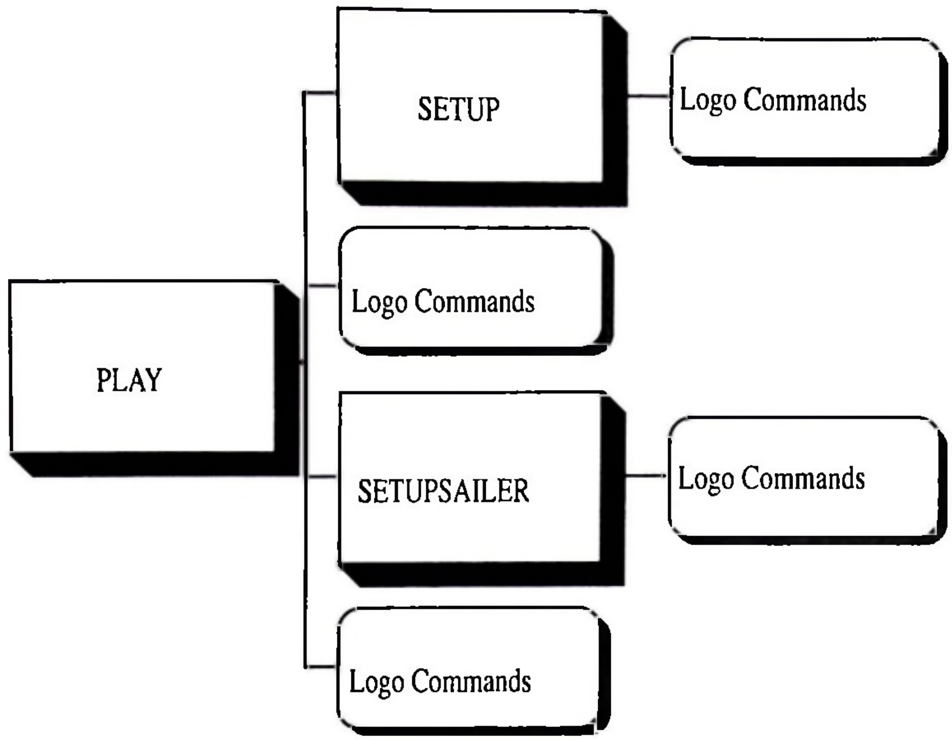

Figure 1. Structural Logic of SETUP and SETUPSAILER

Were you happy with the way your project turned out?
S1: Yes. Because it was neat to see that the computer could do it.
S2: Yes. Because of the way we had to join the information to get where we wanted it.

What difficulties did you have with your project?
S1: Some parts we didn't like, so we had to go back and debug the program and it took kind of long.
S2: Well, my partner was gone for three days and when he came back he had forgot how to work it and messed it up.

Name three things you have learned from doing this project.
S1: How to make words appear on the screen.
How to use more than one turtle at a time.
How to create the animation.
S2: I learned about Logo.
I learned lots about Logo.
I learned the commands.

Overall, how did you feel about your project. Did you enjoy it? Was it boring, too hard, fun, awesome, dumb, or frustrating?

S1: Awesome, because after you made a wrong turn and you fixed it and made it work, it made you feel you can do the rest.

S2: I liked it and I'm glad I had a chance to work with Logo.

Did you enjoy working with a partner?

S1: Yes. On some parts I didn't know how to do, my partner would help me.

S2: Yes. I liked working with a partner because he knew more about Logo than I did.

The preceding example is neither the most sophisticated nor the simplest of the projects. It just happened to be the one at the top of the pile when we were looking for an example. It was included to give the reader a better feel for what the students were actually doing. Analysis of all of the student projects remains to be done. A preliminary overview of the sixth-grade projects is shown in Table 1.

Table 1
Summary of Sixth-Grade Projects

Turtle Geometry tasks		0
Action stories		
Description of a scene	13	
Conflict scenario	8	
Sports scenario	6	27

Research Activities

There have been numerous studies on the effects of Logo. Why add to the list? What new information, conclusions, or recommendations might ensue from one more study? One can take many legitimate paths. One could examine the relation between the type of Logo activities that the student engages in during class time and some form of summative evaluation at the end of the unit. This would follow the traditional paradigm of most school curricula. Alternatively, one could continue to focus on student learning by examining relationships between Logo performance and some set of cognitive and affective factors, or between Logo performance and performance in some other area, such as a particular school curriculum topic or another problem-solving domain (Try, 1989). Or one could attempt to provide a fine-grained analysis of individual student protocols while engaged in Logo activities (Papert, Watt, diSessa, & Weir, 1979). Then again, one could direct attention to the teacher or the school and look for meaningful statements about Logo-related activities (Carmichael, Burnett, Higginson, Moore, & Pollard, 1985; Hoyles & Sutherland, 1989). All of these studies have a researcher or group of researchers examining subjects of interest, metaphorically looking at them through some form of magnifying glass. The metaphor suggests an interesting question: "What do the subjects of the study see when they peer through the same magnifying glass?" In more mundane terms, what do teachers see when their classes are the subject of research? The hypothesis is that much of the impact of a research study is found not only in what the researcher notices but in what the teacher notices as a result of being noticed.

The basic research paradigm is very simple and straightforward. A researcher from a university visits a Logo classroom, makes notes about what he or she sees, and then discusses this with the teacher. This cycle repeats itself.

Representation of an idea is often difficult. Regardless of the approach or perspective that is taken, there are inevitably both advantages and weaknesses. The metaphor of the magnifying glass is a case in point. However, normal text can be problematic as well. How well does the previous paragraph's mention of cycles convey the nature of the study? Early in the study, we envisioned the entire study in terms of a series of Logo procedures, as shown in Figure 2.

```
To Do.Research :time
    If :time = 11 [stop]
    Observe.Classroom :time
    Observe.Researcher :time
    Discuss.Results :time + 1
    Do.Research :time + 2
End

To Observe.Classroom :time
    Interview :teacher
    Examine.supplementary.materials
    Observe :students
    Examine :student.scrapbooks
End

To Observe.Researcher :time
    Interview :researcher
    Examine.research.plan
    Observe :researcher
    Examine :researcher.notes
End

To Discuss.Results :time + 1
    Teacher.comments
    Researcher.comments
    Recommendations
End
```

Figure 2. Study Design in Terms of Logo Procedures

Warren's views on the project are insightful.

The fact that this process was a cyclical or recursive one, which allowed for equal input and assessment from both sides, is what made the impact of this study such a powerful one for me. Figure 3 illustrates the process I experienced.

The initial *action* in this process was when Dale introduced the idea of this study. Acting as the catalyst, Dale began observing my classroom, providing immediate feedback and asking questions. This lead to a great deal of reflection,

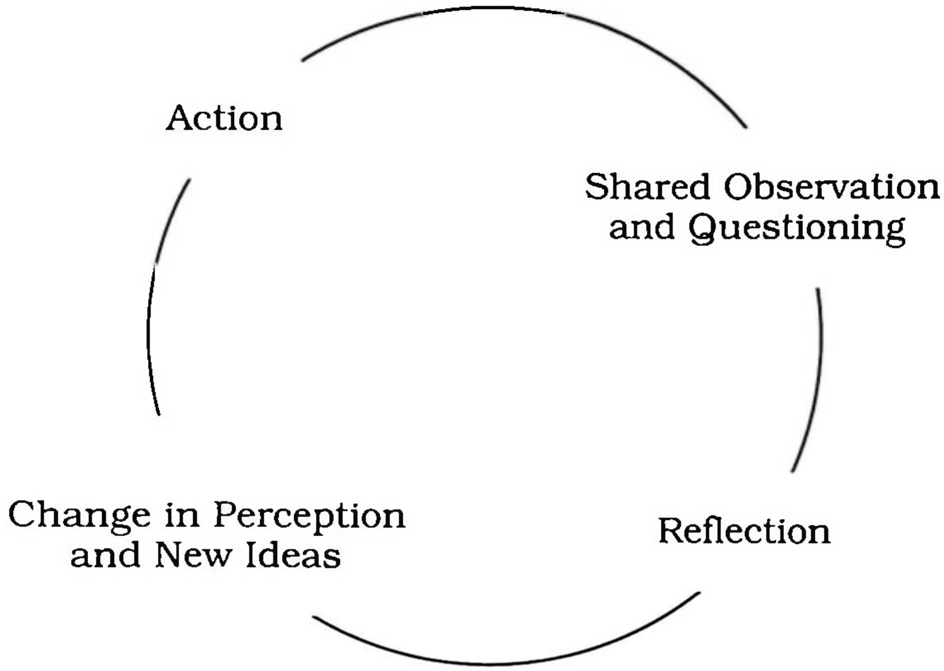

Figure 3. Cycle of the Study

and this reflection in turn lead to a change in my perceptions or to the creation of new ideas. As I mentioned these to Dale, he would reply with the most oft-repeated statement of the project: "Write that down!" The action of writing everything down was an incredibly powerful one for me because it led me to further reflection, to changes in perception and ideas, which led again to further action, shared observation, and so on.

For me, the real power of the project has been in the action phase of this study. Rather than waiting for the results of the study to be summarized, with recommendations given and then applied, this study has resulted in *self-initiated* change (the best kind), even before the study has been completed. Discussing the study, a fellow teacher stated, "It will be nice to apply what you've learned when it's all done." However, because of the nature of this study, change has already been actualized! Application has already taken place and will continue, and that is what makes this process so powerful and exciting for me as a teacher.

What keeps the recursive process going is the acceptance that the magnifying glass does have two sides, both of which bring about the equal balance of interaction. Both the teacher and researcher literally and freely bounce ideas off of each other, and then continue for another round. The key is that as a participant-researcher, I have the luxury of going back into my classroom as a teacher, right then and there, and applying what I have learned. The neat thing about this project is that I have also had the privilege of standing back and watching the researcher in the ring for a while, thus switching roles and then being able to conference again, make decisions, and then actualize more change.

It wouldn't work without the equal participation of the other. The cycle would stop if one dropped out, and it would die if one started to dominate the other. The key is that it has to be an equal partnership for real positive change to continue to occur.

Reflections

Warren Toth, Teacher

Probably no one would dispute the fact that to pause and reflect on one's own teaching has great benefit, but it seems that teachers get so caught up in the process of teaching and all that goes with it that they hardly ever take time to truly reflect on what they are doing, why they are doing it, and what effect they are having on the students not only academically but in building the whole student as a person. In my case, for example, I do well just to keep all of the computers in our school up and running, get my marks done, and get through the day without a major problem, let alone assess how I'm doing, why I am doing it, and how the kids feel about what they are doing.

Through this experience I gained a totally new perspective of my classroom and what I was accomplishing with the students. From Dr. Burnett's visits to my classroom, I learned a great deal from the way he interacted with the students. But perhaps the greatest benefit of all to me was when we discussed and shared what we both observed. Some of the insights that he shared with me included the fact that my students were really interested and keen in what they were doing. He saw students who were doing some extremely complex programming and working with math concepts that were above their "normal" ability. He noticed that students were all doing independent projects, that they were learning and enjoying it, and that they were on task for the entire period, which in a way was a surprise to me. This was, of course, a great boost to realize that I was doing an okay job, and that he wasn't just trying to be nice but rather that he was making some realistic observations of my classroom. From these shared observations and through our discussions, I was able to gain new ideas, approaches, and renewed motivation for what I was doing.

This process of reflection also helped me to realize that over the last four years of teaching Logo my teaching style has changed and that my role in the classroom has become one of a "guide on the side" (Merrit, 1990) rather than that of an instructor or lecturer.

I recalled a statement from an educational seminar: "No child will diminish in hope because of me, but be enhanced in hope because of me!" After reflecting upon this, I began to realize that, yes, my kids are (for the most part) enhanced because of what I'm trying to do in the classroom. They can say, "Hey, I can work with words and concepts in math. I can think for myself and solve problems. I can be in charge. I can create something worthwhile and I can do it on a computer!" And I realized that if I'm instilling those kinds of attitudes in students, I can feel good about what I'm doing.

The discussions we had following the classroom observations soon became very motivating for me as I could see that the learning taking place was, in fact, significant. This motivation spread into a desire to improve in areas that I felt needed improvement. Due to the positive interaction between Dale and me, it was more a self-realization of areas needing improvement rather than Dale having to point out my teaching weaknesses. This made it easier for me to accept the need for change rather than having demands put on me to do so.

One area on which I focused because of the research process was that of student evaluation. I evaluated the students' work more thoroughly than I normally would have, and allowed them to give me more feedback. This point was made evident when, while filling out a questionnaire made for this project, a student stated that the reason she could not complete her project as desired was because I was not in the room when she needed help. This made me realize that I had been allowing myself to be interrupted by other school concerns, computer maintenance, and other teachers' needs more than I realized, rather than making my students' needs my first priority. Fortunately, I was able to discuss this situation with her, apologize, and spend some extra needed time with her to give individual instruction so that her experience with Logo and computers was a positive one. If I had not given my students the opportunity to evaluate my teaching, I would have failed to meet the needs of one of them. Another area in which I realized I needed change was balancing group instruction with hands-on activities in order to allow students to learn at their own pace and complete their projects as desired.

Overall, this project made me take a big step back and look at my teaching from a broader perspective. It allowed me to see the whole picture through Dale's magnifying glass, and to focus on those areas that needed change without narrowing my vision of the potential in my classroom.

I feel that this research project was a positive experience for me; however, there were several aspects that were not all that wonderful. For example, the activities associated with the project took extra time and effort on my part. There were frustrations associated with trying to deal with those areas that needed change. In addition, a considerable amount of stress and pressure related to deadlines came when our proposal for this workshop was accepted. However, even this was good for me because it helped me to be better organized. I guess this process is very similar to what it is like for a student using Logo. In the words of one of my students, "You have to do it systematically, you have to think about what you're doing, but no matter how much work it takes, it's worth it!"

The thinking I've done and the actions I've taken over the past two to three months as a result of this research project have helped me as a teacher and as a person more than I could have ever imagined. At first I honestly thought that this research study would cause burn-out more than anything else, but the exact opposite has been true. It has revitalized me and helped me regain my focus as a teacher. That is far more powerful to me than any set of research-based or administratively imposed recommendations that would have been made had the magnifying glass not had two sides!

J. Dale Burnett, Researcher

What is the impact of a Logo research project? In a traditional sense, the benefit accrues in the published literature and in conference presentations. This is a difficult impact to document because the threads are so tenuous; the connection between something in print or something that is said during a presentation and something that occurs in a classroom six months later is often anything but clear. However, the overall gestalt is reasonably clear. There are numerous stories that essentially say the same thing: "If I (the teacher) had it (some Logo activity) to do over again, I would." And the gestalt carries forward; it is the "big picture" that is the message, not the detail.

However, there is another impact of a Logo research project, one that is not yet well documented. That is the impact at the local level. This report is an attempt to illustrate that this impact is also significant. But like the threads between published research and classroom action, the threads here are also difficult to isolate. Yet the overall impact is likely to be substantial. The primary voice in this article is that of the classroom teacher. This voice echoes at a pedagogical level the same messages that have been heard at the student level: It is encouraging to have someone show confidence in your abilities, it is important to have ownership in your ideas, it is comforting to have a "guide on the side" when you want one. As a researcher, these are principles that I will want to keep in mind as I plan future studies. They are also arguments for conducting more classroom-centered Logo research projects.

As an aside, in the previous section Warren discusses his "teaching weaknesses." This was a revelation to me when I first read that section because I was not aware of such weaknesses! I thoroughly enjoyed being in Warren's classes. I was made to feel comfortable right from the beginning and revelled in the "hum" that pervaded the classroom for the entire period as the students worked on their separate projects. It was Warren's self-evaluation that led him to modify his evaluation procedures. As such, he owns those procedures, just as most classroom teachers own their own routines. People who believe that technology can provide a substitute for this are kidding themselves.

Inclusion of the example of a student project raises a number of questions:

- Focusing on the actual *LogoWriter* commands, what kinds of feedback should be given to the students at this stage?
- Focusing on the structure of the procedures and subprocedures, what kinds of comments should be made?
- Focusing on the storyline of the task, what suggestions should be made about next steps? Or should this be accepted as a completed project, permitting the students to move on to a different project?
- What types of statements can we make about the students' understanding of their project?
- What type of information do we obtain from the students' response to the questionnaire?
- What is an appropriate role for such information in determining a final grade?

- What is an effective way of organizing this type of information across an entire class of students?

What are our next steps? First, to continue. Second, to provide a clear description of a number of student projects. Third, to provide an analysis of these projects. Fourth, to reflect on our overall process. Fifth, to compare grade 4 work with grade 5 work and with grade 6 work. Sixth, to provide a clear description of the pedagogy involved. Seventh, to compare various forms of evaluation. Eighth, to focus on one or two projects for a detailed examination of the student protocols, perhaps emphasizing the role of cooperative learning. Ninth, to examine native student work for evidence of cultural assimilation and accommodation. Tenth, to examine student projects for evidence of gender differences. Eleventh, to extend the project to other teachers and software. Twelfth, to extend the project to other schools. Thirteenth, to be skipped. Fourteenth, to be determined. Logo research is simply a macro version of Logo projects. Educational research is simply a macro version of Logo research.

A final comment on support is appropriate. All researchers are critically aware of how important this can be. When I first mentioned the research project to Warren's principal, his first words were, "What can I do to help?" I continually receive similar support from my dean. Professionally speaking, though we live in an area where the rain seldom falls, this project is located in a Garden of Eden. It is possible to have fun, even when doing research!

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An Action Research Collaborative From a Leader's Perspective

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Crestwood Elementary School, Madison, Wisconsin

"Unless teachers understand the ideas of Logo and how to guide children to use and understand them, the power and elegance is lost." *Dan Watt*

Background

Madison, Wisconsin, offers a supportive setting for action research. Professors Bob Tabachnick and Ken Zeichner of the University of Wisconsin School of Education are two leading thinkers on the topic. University of Wisconsin elementary education undergraduates are required to undertake an action-research project during their student teaching experience, and cooperating teachers frequently become involved. Within the Madison Metropolitan School District, four different action-research groups formed over the past five years. In 1985-86 and 1986-87, the first groups drew together kindergarten through 12th-grade teachers with a range of research interests. During the 1990-91 school year, two groups functioned with specific interests, the Madison Multicultural Action Research Group and the Madison Logo Action Research Collaborative (MLARC).

Madison was one of nine national Logo Action Research sites directed by Dan and Molly Watt of the Educational Development Center. Other sites were Boston, Brookline and Concord, Massachusetts; Chapel Hill, North Carolina; Brattleboro, Vermont Chicago, Illinois; St. Louis, Missouri; and Bellevue, Washington.

Leadership

This writer had the opportunity to lead the Madison site. I felt qualified to do so because of my 10 years of Logo involvement, my leadership training, and the collaborative nature of the group.

I had explored Logo informally through inservices classes and attendance at conferences such as Logo '85. I participated in the 1985-86 Madison Metropolitan School District Action Research Group, studying the topic What Problems Fourth- and Fifth-Grade Logo Users Encounter. I had taught numerous Logo staff development classes for Madison area districts and shared early experiences with LEGO TC Logo at the Logo Institute at Lesley College in 1987.

I also spent a week at a Logo Action Research Collaborative leadership institute organized by the project directors, Dan and Molly Watt. There we shared concerns and questions about leading an action-research group and began acting as a support system for each other. The institute provided us with a leadership notebook, which, together with subsequent mailings, helped me develop a framework for my group's activities and handouts. As we tried out methodologies suggested in the notebook, we built relationships with one another and learned more about Logo, the action-research process, and leadership techniques. When I returned home, I felt confident and knowledgeable about how the year would unfold. I also knew I could reconnect with others in the project for ideas or support by telecommunicating through our bulletin board.

Composition and Functioning of MLARC

Our group was composed of first- through sixth-grade teachers and one educational assistant from each of seven different schools in the city of Madison and outlying suburban and rural districts. During 14 meetings, members reflected on their teaching practices in a systematic way. As the group leader, I guided them through three stages of action research: Looking At, Asking About, and Finding Out (Watt & Watt, 1991).

Time was a precious commodity. Group members went out of their way to attend meetings. I was very careful to stop meetings on time, regardless of our progress, because most people had long drives, work, and/or family demands ahead of them.

I usually set the agenda, provided handouts, took minutes, and collected feedback. Participants brought snacks as a means of doing something special for the group. We experimented with different meeting formats, trying meetings of two-, three-, and four-hour lengths. A four-hour meeting was generally too tiring on a week-night, sandwiched between two teaching days. Two- or three-hour meetings were never long enough, and we often ended because the clock said we were finished, not because the discussion was over.

The purpose of this research group was to support experienced teachers in:

- engaging in collegial reflection and dialogue
- increasing their knowledge of Logo
- developing methods for assessing student learning
- carrying out an action research project
- revising, improving, or developing their teaching practices
- developing more authoritative professional voices
- participating in peer support of research by colleagues
  (Watt & Watt, 1991)

Three Phases of Action Research

Phase 1: Looking At

Meetings in the Looking At stage require more input and direction from the leader than in later stages. Group bonding and talking a common Logo language are important goals at the beginning.

At our first meeting, we created a collaborative Logo Design Quilt (Watt & Watt, 1991). This encouraged camaraderie, fostered a common way of talking about Logo, and offered insight into its value. We started as teachers from seven separate schools and ended as new friends eager for the next meeting. Those who were worried about not knowing enough Logo realized that we would all seek growth in this area together. Feedback from this experience was positive and included this comment: "So many people from different schools are excited about Logo and are all together, sharing, laughing, and growing." One member later used the group's ideas at a parent meeting introducing Logo and the reasons for teaching it.

Ultimately we would need to focus on research questions. What would people's questions be? I was not overly concerned because it seemed too early to settle that issue. Some people were probably surprised by my attention to other things. However, my priorities at this stage were to establish our group, develop a common way of looking at Logo, and make sure that participants understood the action-research process. We had the whole year ahead of us.

In the second meeting, we focused on assessing Logo learning. Looking together at a collection of one student's work was very powerful. We had varied thoughts about the best way for a teacher to intervene effectively. People had brought problems and questions to the group. Others brought articles and resources. We were giving each other support. Follow-up reading included "Assessing Logo Learning in Classrooms" by Dan Watt (1988-89), a series of nine articles.

We began our third meeting with more sharing. One teacher-researcher reported meeting with the computer coordinator and educational assistant at her school to provide information from our first two meetings. They decided to revise their Logo curriculum at that point. A second teacher-researcher had surveyed her colleagues to gauge Logo knowledge. They asked for more Logo staff development. We offered a six-hour course. A third participant echoed the same needs for her staff. Finally, filled with much new information and ideas, a fourth quietly wished she could start the year over and do things differently.

I realized with excitement that we were:

- critically examining our practices
- engaging in reflection and dialogue
- increasing our content knowledge of Logo
- developing assessment methods
- starting to carry out an action research project
- revising, improving, or developing teaching practices

We used a brainstorming session to generate a list of possible action-research questions (see Appendix A). Before anyone settled on a specific question, I wanted to be certain we had collectively considered a wide range of possibilities. As we developed our list, we became immersed in phase one of the action-research process. We broadened our thinking, yet the variety of questions also confused us. What would be the best question?

For our final meeting in this Looking At phase, participants wrote a short paper describing the context of their classroom. Professor Bob Tabachnick, University of Wisconsin School of Education, agreed to talk with us at that meeting. He opened by sharing his thoughts about the basic elements of an action-research question. He emphasized that the purpose of action research goes beyond curiosity, to seek a way to benefit learners.

Questions, he told us, need to be worded in an active way. He divided our potential questions into two categories:

1. How do I help children do more of something?
2. What happens if/when something is done?

Reviewing our list, he wondered about rephrasing the first question to focus on children. Could the second question focus on sharing and grouping all children according to mutual interests? Might we reword the fifth question to, "If I do this, what will happen?"

As we analyzed our list of questions, we talked extensively about students working with partners. One member concluded our discussion by suggesting that we each ask a different action-research question about a common topic—partnering. Through the telecommunications network, we were aware that the Bellevue, Washington, site was considering a group question such as this.

We felt surprised and excited at our idea to pursue a question in a way that gave each person freedom to pursue an individual interest within a group question. We concluded the meeting with that decision.

A snowstorm delayed the fifth meeting and prompted extensive phone communication between myself and group members. Individually, people began expressing reservations about a group question. The first member to call me expressed interest in examining third-graders' use of procedures but hesitated about pulling away from the group. Others expressed similar ideas about researching their own questions. The group actually wanted to pursue separate questions rather than a group question.

Looking back, identifying questions that were worth asking and answering was a critical aspect of our entire action-research process. Bob Tabachnick helped us recognize that we did not have to prove that something was true. To discover and describe carefully what children say and do under certain conditions had its own value. Furthermore, to ask and try to answer a question that was important to each of us rather than try to satisfy any predetermined pattern was also important.

Phase II: Asking About

The steps of the Asking About phase included developing a strategic plan, refining it, and collecting data. The group shared considerably more at this point than at earlier meetings. Topics included Logo activities, action-research thoughts, teaching practices, and progress reports related to previous discussions. I met with each teacher-researcher individually at her school, and when possible, with her principal. We developed individual and collaborative strategic plans, using the Action Research Planner and Question Focusing Process (Watt & Watt, 1991), and identified specific data-collecting techniques.

Our final research areas (see Appendix B) included gender-based issues, learning tools to empower first-graders, at-risk first-grade learners, cooperative learning, conceptual readiness of third-graders for Logo procedural use, problem-solving strategies of fourth-grade Logo users, peer teaching, and connections to other curriculum areas such as math and language.

Our sixth meeting opened with spontaneous and powerful sharing about Logo classroom activities and the action-research process. One person shared activities based on a handout, Pre-Logo Games (Kull & Cohen, 1989). Another was already putting her strategic plan into action. She excitedly shared the LEGO TC Logo work her sixth-grade students were doing. A third shared her thoughts and experiences from a previous action-research experience, What Math Do First Graders Learn Messing Around With Logo? She stressed the importance of pursuing a question that has meaning for the teacher-researcher and using comfortable techniques to collect data. She did not want to go home and listen to cassette tapes or watch videos after teaching all day! "Be yourself. Use this opportunity to reflect," she advised the group.

People spent the second part of the meeting writing strategic plans in small groups. Candy thought aloud about her second-graders creating a class bank of word problems. Karen predicted potential pitfalls based on her own work producing a student newspaper with *LogoWriter*. I asked the participants to complete their strategic plan and bring it to the next meeting.

The following three meetings were the core of the Asking About phase. Individuals shared their questions, plans, and data-collection methods. Using the Question Focusing Process, colleagues offered ideas, asked clarifying questions, and gave encouragement. Although I had envisioned this happening in small groups, everyone insisted on a large-group format.

In retrospect, I think a large-group format was important to group members because each participant offered a different perspective based on her teaching situation and/or research focus. Sometimes participants benefited by hearing from colleagues at their own school, and other times they benefited more by hearing an outside voice. Whole-group discussions allowed both. The group also gained energy and insight from the sharing that took place among various group members who could talk at length between meetings. Those people had many conversations beyond our meetings, thinking about their questions, strategies, data, and findings. It was a delicate balance for me as the leader to help the group benefit from these extended discussions rather than to feel isolated by the fact that they took place.

During our January question-focusing meeting, we ran out of time, and those who could, agreed to stay an extra hour. We also agreed to meet the next week to finish this process because this was not an activity that could be stretched out over a month. The participant-researchers had reached a point where they needed to focus their ideas with the help of the group. The first members to focus their question in this manner thanked the group enthusiastically for its support and expressed strong positive feelings about the process. This powerful example of collaborative support among group members created an eagerness among the others to share the same experience. Sometimes it took the whole group commenting gently in different ways to help a person hear our voices and consider suggestions. At other times we needed 11 people to think about what it was we were trying to say. Feedback and support from others was valued.

Patricia Wood, a local teacher, has done classroom action research on a yearly basis. We read her paper "Action Research: A Field Perspective" and invited her as a guest. We drilled her with practical questions about data collection. She stressed simplicity. She talked about reading work by experts on topics related to her questions, the importance to teachers of writing, and finally, the need to start with a good question. According to Pat, "A general question can cause you to go on for a month or two before focusing." Did we have 10 good, focused questions?

The final meeting in this phase focused on the importance of student authoring and on a continuation of previous discussions on critically assessing Logo learning. We had two guests, Betty Wottreng and Rich Lehrer, coauthors of *Seeding Mindstorms*.

Betty is a second-grade teacher and building computer coordinator in Verona, Wisconsin. She and Rich have co-led a summer LEGO TC Logo institute for teachers and students. She shared her Logo and LEGO TC Logo experiences with our group. We were eager to hear her day-to-day success stories with young children, Logo, and critical thinking. Betty was pleased to meet other teachers who shared her interests.

Rich is a professor in the Educational Psychology Department at the University of Wisconsin, Madison. He is a research practitioner who analyzes critical thinking in computer-based environments. He is working on a university-based math project, Cognitively Guided Instruction (CGI Math). Three MLARC members were deeply involved in piloting this project and had been thinking about connections between CGI and Logo all year. Rich shared their interest in children's mathematical thinking, in promoting children's sense of ownership of their work, and in Logo as a tool for thinking.

Since this meeting, teachers at two other Madison CGI pilot schools have decided to integrate Logo into their math curriculum. More information about this connection will emerge as teachers use both Logo and CGI Math in their classrooms.

By this time, MLARC was recognized as a source of information about Logo by other teachers, principals, and school administrators. We published a single-issue newsletter, *Logo News*, and offered a three-session introductory Logo course.

Phase III: Finding Out

The final phase, Finding Out, is in process at this writing. We have analyzed data, written drafts of final reports, and edited our work with our peers. Support for our writing and editing came from two resources, the Action Research Report Planner and the Work-in-Process Guide (Watt & Watt, 1991).

We spent two meetings looking at and learning about each other's data. Most people made data packets to share key data samples with others. Members who taught at a school together reported talking a great deal among themselves outside of our meetings. We learned a lot about analyzing data. We wished for more of certain types of data and less of others. The nature of some data lent itself more easily to charts and tables. Other data was equally important, but cumbersome or elusive. Sorting data and making sense of it was a challenging step.

Teachers have not often had the opportunity to write. Tension pervaded the group. Samples of other action-research papers handed out during the year became important reference points. Once we began sharing and critiquing first drafts, everyone relaxed. We were a support system for each other.

During our final meeting of this year, members reflected on the impact of the action-research process. Here are some questions and participant answers.

In what ways have you revised, improved, or developed your teaching practice since LARC began?

- "I have increased student time at the computer." (three comments)
- "The curriculum has been changed to a more holistic, playful one that emphasizes projects and processes rather than step-by-step programmed instruction. My teaching team and I have more student journal feedback and student reflection. Two other schools in our district will probably follow suit."
- "Less looking at products mastered, less worry about curriculum coverage. More interest in exploration. As a teacher, I am less pressured. I have more confidence and trust in the kids. I never would have done this without LARC."
- "More exploration time."
- "We are trying to integrate Logo across the curriculum into math, whole language, and social studies."

What aspects of the collegial dialogue impressed you the most? What did you find perplexing or confusing?

- "I enjoyed the exchange of ideas and suggestions given to me. I felt the group was extremely professional and helpful. It elevated thoughts about my profession."
- "I was impressed by the professional, thoughtful comments and discussion that our group had. People were open, honest, and willing to share."
- "The discussions gave me support to change."
- "So professional." (three comments)
- "The discussions gave me respect for teaching, each other, and our work."
- "The discussions showed the influence of the Watts—the importance they give teachers and communication, their trust and warmth."

Describe how your assessment of student learning has been influenced by LARC.

- "I am a much better observer. I realize the power of observation. I am more likely to take notes on what I see and hear happening in my room."
- "I have a deeper trust in students and their journals."
- "Now I look at how a child is thinking and build on what that child knows. My 21-year habit was to look at what was wrong, what needed changing. It is hard for me to change. I feel less pressure to cover the curriculum. I have an increased awareness of peer teaching."
- "I look at their graphics and their procedures now."
- "Teachers of younger children often ask students to tell about their work because

it is not always clear. Teachers of older children rely on the end product too often unless it is not clear. We need to ask all children to explain their thinking more often."
- "When we ask children what they are thinking, it shows we care. We make them more aware that we are interested in the process. This also leads to changes in our practice."

Conclusion

Eleven of us can say that we have collaboratively

- rethought our practices
- shared professional questions and issues
- expanded our Logo knowledge
- used new ways to assess student Logo work
- almost finished an action-research project

Specific examples can be seen in all of our classrooms. At-risk first graders are becoming emergent learners. We can assess their work and see they are predicting, analyzing, and asking meaningful questions about Logo. One student who was a nonreader is now reading Logo commands with enthusiasm and confidence. A teacher who used to be very structured is beginning to experiment with more unstructured time and to increase her own comfort level. She has rethought her teaching practices of many years as a result of our group discussions. Several teachers report a greater awareness of how they group children, and are committed to allowing children to construct their own learning as often as possible. As a group we agree that we are much more aware of how children are thinking.

We are being asked to serve on summer committees, to present what we have learned at workshops, and to lead staff development classes during 1991-92. There is some discussion of forming new action-research groups. As we conclude our research cycle, MLARC has decided to continue meeting on a regular basis in order to support our continued growth and change in the coming year.

At a joint meeting of the Chicago and Madison LARCs at the 1991 American Educational Research Association, Dan Watt reflected, "One of the original intents of Logo was to develop a community of learners. The action-research process has created a community of teacher learners." At the same meeting, Molly Watt concluded, "There is more to this than learning about action research. The teacher self-empowerment that takes place is ours forever."

In our area, 11 teachers and more than 500 students have benefited from the 1991-92 MLARC. According to one MLARC member, "Action research is one of the most exciting things that has happened to me as a professional and as a person." As the year draws to a close, the last meeting marks a new beginning.

Acknowledgments

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APPENDIX A

Brainstormed Question List

1. What can I do with an educational assistant who can work with students for 3(
minutes per day but knows no Logo?
2. What are some effective ways for students to share their work?
3. How can I provide a variety of effective opportunities for students to share work with each other and other classes, in the district, the country, and the world?
4. How can Logo become an integral part of my math curriculum, especially problem solving?
5. What connections does Logo have to my current math program, Cognitively Guided Instruction (being developed at the University of Washington by Fennema and Carpenter)? Is there a correlation between CGI learning strategies and Logo?
6. Is there an advantage to students working predominately with partners? Individually?
7. How does 15 extra minutes in the computer lab affect instruction?
8. What is relationship of SCIS Relative Position and Motion to Logo? What other off-computer units may have value?
9. What is the impact of the use of procedure trees on Logo teaching and learning?
10. What is the impact of once a week in the lab versus classroom setup?
11. What would older kids think is important to teach younger kids about Logo?

12. How can we maximize peer-sharing of strategies, thinking, questions?
13. What transference of Logo takes place across the curriculum (estimating, geometry, measurement, etc.)?
14. Can I design a question that grows with a child (such that I can collect data next year and the next year)?
15. What kinds of things can students act out, role play, and do with their bodies (orienteering) that will increase their understanding of Logo?
16. Learning styles. Special education students...what can I ask!!!
17. When should students start using procedures? Variables? At what age do most children (developmentally) understand certain complex Logo ideas?
18. How are "low" kids doing with Logo?
19. Does Logo success energize learning in other areas?
20. We need one more to make this list even!!!

APPENDIX B

Final Question List
Madison LARC March 1991

SUE BARTH: How does working with a partner or working alone enhance or hinder student attitudes and performance?

Sue designed a children's version of the four feedback questions to gather data from her third-grade students on a regular basis. Students completed a sociogram at an early stage of data-gathering to see social interactions from the students' point of view. This will be repeated at a later date. Sue also asked students to indicate their preference for working with a partner or alone. She wants to know why and when they choose to work alone or with a partner. Early research hinted that sharing of student work played a key role in encouraging working relationships among classmates; thus, sharing of student work has become an important focus for Sue. Other data sources include teacher observations and daily notes, dated student work samples, and student journals.

SUE BERTHOUEX: What tools will empower first graders using Logo?

This is Sue's second Logo action-research project. Previously the students in her first grade have done a lot of exploring with Logo, mainly focusing on wrapping. Currently, she is incorporating more teacher-student interactions to determine how to provide additional support for children as they structure their own Logo learning. Sue is developing and exploring ways both on and off the computer to support young children beginning their Logo learning. She is noticing children's understanding of directionality. Students have drawn shapes like rectangles, squares, and triangles and have used color to draw lines, fill shapes, and backgrounds. They work alone and with partners, planning in their journals and working at the computer. She is working to integrate whole language, Cognitively Guided Math (CGI), and Logo. Data sources include teacher observations, student journals, work samples, and lesson plans.

DAWN DALY: What do fourth graders think is important to teach first graders about Logo and how do they go about it? What debugging strategies do students use?

Dawn's fourth-grade class has done activities with a first-grade class since September, including reading books together, creating holiday projects, and singing. In January the relationship became more permanent with bimonthly computer times. Dawn is investigating if this is an effective way to introduce *LogoWriter* into her school. She is gathering data from older and younger student work samples and logs, from audio/videotapes and photographs, and from her own observations and those of the first-grade teacher. In addition, she will explore the Big Buddy system in her school and other older-younger pairings in area schools to gain ideas and strategies for this computer relationship. The debugging question met with silence when first posed to her students. Dawn wants to explore how she can improve students' thinking/problem-solving skills by building their awareness of useful strategies.

SYLVIA GREEN: After introducing procedures to third graders who know primitives, to what extent will they use them and how might I encourage growth in procedure use?

Sylvia's third graders use the immediate mode, have a solid knowledge of basic primitives, and practice procedure use with structured teacher direction. Logo activities vary throughout the year. Some examples include creation of houses, acrostic name poems, initial procedures, and monograms. Sylvia plans to analyze student work samples over time, videotape students working at the computer, and record teacher observations. She has volunteered to teach an after-school enrichment class on Logo and may use student work from this experience to verify data collected during the school day.

MARIANNE JACKSON: How do the strategies used by fourth-grade students to solve a Logo project correspond to learning styles?

Marianne is examining strategies that each type of learner chooses so that she can determine which are most frequently used in successfully completing a project, which facilitate getting the job done in a reasonable time, which inspire thinking (though they may not serve the explicit goals of the project), and which are creative, fun, and exciting to the student. Logo activities will focus on designing a crossword puzzle to share information about a famous Wisconsin person. Marianne and her students have designed a Strategy Checklist. Sources of data also include student Logo portfolios with weekly journal entries, drawings, printed projects, and procedures as well as teacher field notes, including student observations, dated interventions, a record of new practices introduced, and the Strategy Checklist results.

ANNIE KIETH: What will first graders who are struggling academically do with LogoWriter?

Annie teaches Logo in a way that promotes student ownership of work. A school district mentor for Cognitively Guided Math, Annie believes that children construct their own knowledge and learn by building on it. She teaches Logo based on her knowledge of the children's understanding. Her students keep journals of ideas, work plans, and questions. Early lessons explored what students knew collectively about Logo and about squares using a webbing procedure. Annie read aloud Ed Emberly's book *Turtle Talk* to generate some beginning ideas and questions, followed by student brainstorming about what to do next. Logo activities will be generated from class discussions, sharing of individual work, and teacher suggestions. Data sources include teacher and student journals, observations of students during computer and noncomputer times, and interviews with students.

DONNA LANDSMAN: How does gender affect a student's approach to LEGO/Logo? How do I increase girls' motivation, initiative, and problem solving depth using LEGO/Logo?

In answering this question, Donna grouped students in two different ways and assigned two different projects to her sixth-grade students. During the first project, students grouped themselves and the result was all-boy or all-girl groupings. They worked on LEGO-Logo projects from the idea booklets. During the second assignment, Donna created mixed groupings, and the assignment was to make a LEGO creation using one's imagination. Data sources included student journals, teacher charts, a videotape, and teacher anecdotal records. Donna read articles on gender issues in *Logo Exchange* and *Science Teacher* and checked attendance lists at voluntary LEGO workshops to tally the gender of student participants at workshops outside of her school.

CANDY NERGE: What types of story problems will children write using LogoWriter to create a class bank of word problems?

Candy is interested in analyzing student work in regard to CGI math skills and the learning of Logo skills as students create and illustrate word problems. Working at a classroom computer, students will be able to enter story problems on a disk, write in computer journals, and look at other students' work. Initial problems will be on any subject. After a few rounds and the emergence of a comfortable system, Candy hopes to have students write problems about Logo pictures they have created. Candy is fascinated by the CGI/LEGO/Logo emphasis on the child's formation of his/her own body of knowledge. Some resources she has read to support her work include *Young Children Reinvent Mathematics* by Kamaii, *Mindstorms* by S. Papert, *Cognitively Guided Instruction Readings* by Fennema and Carpenter, and articles about the seven areas of intelligence.

RUTH PAULSON: Are LogoWriter projects more complex and creative when done individually or with partners?

The computer lab at Cottage Grove Elementary has approximately one computer for every two students. Is this a reasonable plan? Ruth thinks students in some partnerships produce work that shows better thinking than in work done individually, but wonders about requiring all students to work with a partner at all times. She plans to assign students to work alone or with a partner during several projects. Logo activities for this research project included street scenes, face creations, name procedures, spring greeting cards, and reproduction of an existing graphic. Ruth will collect student work as well as her own observations and those of an educational assistant and a parent. She will also interview students and other fifth-grade teachers and will observe another fifth-grade class. As she gathers preliminary data, Ruth is finding her interventions are not limited to Logo skills but include social skill development as well.

KAREN STREMIKIS: What is the effect of producing a monthly newspaper on fifth-graders' writing skills, social interactions, and computer skills?

Karen helps a fifth-grade class produce a newspaper on a regular basis. Students brainstorm to generate articles that are important to their lives. Partners then take responsibility for article writing and illustrating. Partners are assigned by the classroom teacher to work together for extended time periods. Data includes the newspapers, Karen's anecdotal records, interviews with the classroom teacher, and a questionnaire answered by students.

Increasing Cooperative Behaviors in an Urban Middle School Classroom

Patricia Rowe
Thompson Middle School, Dorchester, Massachusetts

This article reports on my investigation into collaboration among the students in one of my sixth-grade Logo computer programming classes. I tried to learn how collaboration operated in my room and how the students thought about it.

I work in a middle school in Boston in which there are 340 students in grades 6, 7, and 8. The school is located in an inner-city neighborhood that has recently experienced a sustained outburst of juvenile violence. The interaction among students is characterized by verbal hostility, insults, and putdowns. This constant verbal confrontation and aggression frequently erupts into fistfights. The prevailing attitude toward adults is anti-authoritarian.

My classroom contains 15 Apple IIe color computers and three printers. I usually teach seven different groups of students per week. Some of the classes contain about 25 students and some only half that number. The sixth-grade class on which I focused my research included 25 students so that 2 students usually were working together on each computer. Other characteristics of the group were that approximately one-third of the group were special-needs students, and there was almost a balance of boys and girls. I worked with each group of students three times per week. I used *LogoWriter* for the first time with my research class. I had previously used *Terrapin Logo.*

Teaching Goals

In my Logo classes I have two types of goals—academic and process. My overall academic (content) goal is to have the children obtain a reasonable degree of mastery of the Logo programming language.

For this research project, my specific academic goals were:

- to expose the students to the mechanics of *LogoWriter.* I wanted them to learn how to use the command center, flip the page to record procedures, move the cursor from the command center to either the edit screen or the drawing screen, stop a procedure, change colors, clear the screen, and save work.
- to review and (for students with no background in Logo) to teach the fundamental Logo drawing commands FD, BK, ST, HT, PU, PD, and REPEAT
- to get every student working with procedures as an automatic step in creating pictures on the drawing screen
- to acquaint students with features of *LogoWriter* that are not available in other versions of Logo, such as: using multiple turtles, simple animation, changing the turtle shape, editing the turtle shape, creating new turtle shapes, typing on the

The advent of new computation and information sciences has empowered scientists and even average citizens to acquire powerful new skills to identify and solve complex problems thought to be unimaginable or unsolvable only a few decades ago. In short, many people have concluded that we are not making the changes necessary to prepare our children. Schools are changing, but their changes are insufficient.

The Teacher as a Researcher

Even with all this uncertainty, the success of our educational system rests on the performance of teachers, no matter what local or national reforms are proposed or implemented. Teachers by necessity are central to any reform and will be instrumental in its success. However, if teachers are to be the catalytic agent for change during this transition, they must seek and experiment with new ways of responding to new and ever-changing demands.

How can teachers help meet these demanding new challenges? Clearly, teachers must learn to use the new intellectual tools that are an integral part of the scientific and technological revolution. In order for students to benefit, teachers must develop new ways to incorporate these tools into the classroom.

Teachers can use research in three ways to improve teaching and learning. First, they can study how to apply to their own teaching new cognitive research on student learning of modern science and mathematics. Second, they can improve their professional judgment by studying those practices. Third, they can share their collaborative efforts and classroom research findings by using telecommunication and information technologies.

As a result of the changing nature of science and technology, a paradigm shift has occurred in recent years in science and mathematics education. Studies of various disciplines have found that the distinction between experts and novices is not necessarily in the factual information held by the expert, but in the way the expert thought about problems. While textbooks tend to focus on the formal structure of a discipline and the factual information within it, they do not usually discuss the problem-solving and cognitive skills necessary to become an expert. Therefore, emphasis has changed from "learning" to "cognition." Many people now feel that it is no longer sufficient to lecture students about factual and declarative information and have them repeat it on tests. Instead, the emphasis now is on teaching the cognitive and thinking skills necessary for problem-solving. Students must gain a deeper understanding of the processes involved in doing science and in using higher-order skills as experts would in solving problems.

However useful these insights may be, however, they are not sufficient. Large-scale research findings can only supplement actual classroom practice. More times than not, research identifies important problems but does not provide specific guidance on how to solve them. Such research is usually based on normative studies of large samples of students and teachers, covering numerous variables with the aim of achieving broad generalizability; teaching, for the most part, is a clinical activity.

Teachers can benefit by using research methodologies to apply research findings in their classrooms. The teacher can use the systematic techniques of the researcher in the classroom to adapt generalized research findings to a particular educational setting and thereby generate new clinical information that can in turn be reapplied. The collection and sharing of classroom experiences can create a new body of applied clinical knowledge that can strengthen the profession.

In summary, the teacher-as-researcher can use results from well-controlled, normative research for teaching new concepts and using new methods in the classroom. However, actual teaching performances will not improve unless teachers conduct their own tests to evaluate those findings as they apply to their own classrooms. Teachers can assess the outcome and modify their teaching accordingly. Sharing that clinical knowledge with other teachers is equally important. This information-sharing can create a critical mass of teachers with both theoretical and applied knowledge who can have a significant impact on the quality of science and mathematics education.

Cognition, Problem-Solving, and Technology

Many educators have adopted a "constructivist" paradigm to learning. That is, students can be given information, but they must construct information for themselves if they are to understand it and apply it. However, Dr. Seymour Papert, one of the co-inventors of Logo, has extended this approach to include the use of technology. In the constructivist theories of psychology, he says, learning is viewed as a reconstruction rather than as a transmission of knowledge. Papert has extended this approach to a theory he calls "constructionism." He asserts that the idea of manipulative materials is extended to include the idea that learning is more effective when the learner constructs a meaningful product as part of an activity. The student is encouraged to define a problem, write a solution to the problem, debug it, and finally make it do something that will solve the problem. In this way the student learns and develops the necessary skills for defining the problem and the tactical, practical problem-solving skills necessary to solve it.

The constructionism approach changes the purpose of introducing computers into the curriculum, from "computer literacy" to "computer fluency." At a very early age, students experience computers as important tools for solving real problems. The computer provides a new basic skill for the student who will be the knowledge worker of the 21st century.

We live in uncertain and changing times, and the demands placed on education are increasingly difficult to meet. To paraphrase Albert Einstein, everything has changed but our thinking. As teachers we must now view the world as it is and will be, not only as it has been. Science has given us new knowledge and powerful intellectual tools and technologies. We must build upon these resources by finding new ways to incorporate them into the classroom if we are to effectively prepare our children for the world in which they will live. The research efforts described in this volume are important steps in the national effort to improve the quality of education.