DOCUMENT RESUME

ED 128 181 SE 020 957

AUTHOR Abelson, H.; And Others
TITLE LOGO Progress Report 1973-1975. Artificial Intelligence Memo Number 356. Revised.
INSTITUTION Massachusetts Inst. of Tech., Cambridge. Artificial Intelligence Lab.
SPONS AGENCY National Science Foundation, Washington, D.C.
REPORT NO LOGO-22
PUB DATE Mar 76
GRANT NSF-EC-40708-X
NOTE 22p.
AVAILABLE FROM The Artificial Intelligence Laboratory, 545 Technology Square, Cambridge, MA 02139 ($1.30)

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS *Artificial Intelligence; Computer Oriented Programs; *Educational Environment; Educational Research; Instruction; *Learning Theories; *Mathematics Education; *Research; Science Education

ABSTRACT

This report outlines the accomplishments of the LOGO project of the Massachusetts Institute of Technology's Artificial Intelligence Laboratory during the period 1973-1975. Three major areas of work are listed: (1) building learning environments, (2) the theory behind the environments, and (3) experimenting with learning environments. Advances in the design of computer hardware and software are reported; these led to expansion of the activities and the grade levels of students using the system. Advances in theory are reported in six content areas: mathematics, physics, biology, music, games and simulation, and language. Experiments related to teaching, Piagetian psychology, learning laboratories, work with secondary-school and college students, and learning experiments are reported. Goals for 1975-1976 are listed in each section. (SD)

ED128181

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ARTIFICIAL INTELLIGENCE LABORATORY

AI Memo 356

Logo Memo 22

Logo Progress Report 1973-1975

H. Abelson
J. Bamberger
I. Goldstein
S. Papert

September 1975

Revised March 1976

ABSTRACT

Over the past two years, the Logo Project has grown along many dimensions. This document provides an overview in outline form of the main activities and accomplishments of the past as well as the major goals guiding our current research. Research on the design of learning environments, the corresponding development of a theory of learning and the exploration of teaching activities in these environments is presented.

The work reported in this paper was supported by the National Science Foundation under grant number EC40708X and conducted at the Artificial Intelligence Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.

Contents

Logo Progress Report

The basic theme of the Logo Project is the design of new learning environments. This endeavor is grounded in both theory and experiment. The theoretical foundation is a new approach to understanding knowledge and learning based on the computational paradigm. This novel view of psychology and epistemology has led to both the construction of devices that support a far more active learning environment as well as the reformulation of curricula in ways more consonant with the nature of learning.

The experimental activity involves designing teaching and learning activities around these environments with students of different ages and backgrounds. Feedback from these experiments is vital to the debugging of the learning environment and of the underlying pedagogical theory.

The overview provided in this report is organized into an outline with the major headings:

1. Building Learning Environments
2. The Theory Behind the Environments
3. Experimenting with Learning Environments.

We hope that this division into separate headings does not result in a distorted impression of our work: It is crucial to our intellectual approach that we do *not* separate the design of computer devices from the development of new content areas, nor the creation of educational computer languages from careful investigations into the nature of knowledge and learning. For the purposes of this report, however, we have divided things up in precisely this way in order to more clearly highlight specific accomplishments and goals. (For a general description of the project's goals, the reader is directed to the original proposal "The Uses of Technology to Enhance Education," published as M.I.T. Artificial Intelligence Memo 298.)

The sections of this report are modular and the reader is invited to use the table of contents as a guide for choosing those sections which are of greatest interest.

1. Building New Learning Environments

1.1 Educational Devices

Two years ago, the Logo project had developed a collection of mobile turtles, some with touch sensors, a music box and several kinds of graphic displays. During the past two years, new kinds of devices have been constructed. These are listed below.

1.1.1 Light-Sensing turtles

The first version of a seeing eye turtle was designed during 1973-1974 by T. Callahan and D. Alpert. A single photo cell was coupled to controlable mirrors to allow the turtle to direct its sight in different directions and different inclinations without actually moving. Experiments with this turtle led to projects dealing with feedback and coordinate systems (discussed in section 2.1.2 below). During 1974-1975, we also began work on a second generation "eye turtle" which incorporates an automatic scanning mechanism and a linear retina, and we expect this device to provide a forum for teaching about signal processing and functions (See section 2.1.3.). A goal for 1975-1976 is to complete construction of this device and to develop the associated projects.

1.1.2 Digital Logic

During 1973-1974, we explored the realm of digital logic design as a new domain in which students could explore fundamental cognitive ideas. A project which illustrated this was that of designing "turtle ears". This project allowed the student to address in an active way concepts which involve, on one hand, the nature of problem solving, planning and debugging, and on the other, the physics of sound and the nature of time. Preliminary work has been done to make this domain accessible to students by designing digital logic lab stations that can link with the Logo computer.

A goal for 1975-1976 is to complete the design of such stations and continue the development of this project area with students.

1.1.3 Echolocation

The work on "turtle ears" mentioned above led to the construction of a "turtle bat" which utilizes a computer-controlled sonar system. We have not yet developed this to a stage where it can be conveniently used by children, but a goal for 1975-1976 is to do so in conjunction with work on the physics of sound.

1.1.4 Operational Amplifiers

During 1974-1975, J. Lindquist began work on a different area of electronics based on making operational amplifiers conceptually and materially accessible to young students. This has resulted in the development of a first "op amp construction kit." A goal for 1975-1976 will be to test this kit in a variety of teaching situations.

1.1.5 Terminals for Very Young Children

For some years we have experimented with special control devices such as the "button box," designed and built by R. Perlman, one of our graduate research assistants. This is a computer input device which has keys for turtle commands, numbers and the primitives needed to create procedures. Using the button box instead of a full typewriter keyboard greatly improves the ratio of "action obtained" to "frustration" for very young children. This year experiments at the first grade level were much more extensive and systematic than previously. Our ability to use the button box grew substantially. So did our awareness of its limitations which has been translated into the design of several alternative initiation devices. One of these, "the slot machine," has been built by R. Perlman in collaboration with D. Hillis, an undergraduate at the lab. The slot machine allows programs to be physically constructed by placing cards in slots. The cards are marked with visible symbols (to be read by the child) for particular commands and carry corresponding punchout hole codes to be read by the machine.

During 1975-1976, a goal will be to interface the slot machine with the computer and run experiments on its merits as an introductory programming medium for the beginner.

1.1.6 Light Sensing Plotter

We have experimented with a novel way of using a plotter with a photo-diode in place of the pen. This provided the background for a number of projects in pattern recognition carried out by a class of high-school students under the direction of N. Rowe, an MIT undergraduate.

1.1.7 Electric Trains

During 1974-1975, another group of high-school students, under the direction of J. Evans, constructed and experimented with a "computer-controlled transportation system" by attaching the switching mechanisms in an electric train set to our computer.

1.1.8 "TV" Displays

The first Logo display system involved the use of vector-display generators. Such displays suffer from the problem of being limited in the amount of picture that they can display before flicker becomes noticeable. The decrease in the cost of memory makes feasible an alternative -- raster scan TVs -- that allow arbitrary amounts of information including patterns and textures to be displayed.

During 1974-1975, R. Lebel completed the construction of our new raster scan displays, and these are currently being integrated into our computer system for use with children during the fall.

Goals for 1975-1976 are to design projects that take advantage of the capabilities provided for drawing solid areas, gray scales and color.

1.1.9 Remote Displays

During 1974-1975, some members of our research group also participated with M. Minsky in the design of another, conceptually very different, display system. A first version of this system was built and led to a thorough re-design which is now completed. The "Minsky" displays have the advantage of operating remotely over telephone lines and of serving as prototypes for the design of a new educational computer (See section 1.2.4.). A project for the coming year is to construct prototypes for incorporation into the Logo system and experiment with their unique capabilities for educational applications.

1.2 Computer Systems

1.2.1 The SITS Timesharing System

Originally Logo was implemented in assembly language on the PDP-10. In order to provide a computer system dedicated to educational use, it was adapted for the PDP-11. The first milestone in this direction was the completion in 1973-1974 of a dedicated timesharing system running 11LOGO.

This was not an entirely satisfactory solution because of the inability of the system to be self-maintaining or to run other languages or special purpose jobs (like a simulation environment or an educational real-time game). During 1974-1975, our programming staff, under the direction of R. Lebel, completed the design and implementation of a general purpose multi-language timesharing system for the PDP11/45. The SITS timesharing system was developed to provide an environment suitable for running Logo and other PDP11/45 programs. It incorporates a Multics-like tree structured file system including (potentially) full access control. It also provides unique capabilities for running programs as multiple process systems, rather than the more common single process approach, and the ability for each user to run many jobs simultaneously. The system includes provisions for using both the older refreshed displays and our new raster displays.

1.2.2 Modifications to the Logo Language

The Logo language has never seemed to us to be a completed entity. Gradual evolution has occurred over the years, making the language more powerful and convivial for children. During 1973-1974, such features as decimal arithmetic and arrays were added. This was made necessary by various projects for children requiring their use.

During 1974-1975, additional modifications included extension of the filing system, the development of a "real-time editor" made possible by our TV displays, and new commands to allow for "instantaneous response" from keyboards and switches. For example, one can now write programs which cause the teletype keyboard to simulate an organ keyboard. This facility also came in useful in our work in physics (Section 2.5.1) and in implementing the Fastr system (Section 1.3.1.2).

A current issue is whether we now have enough experience to radically redesign the language. This is discussed separately below in section 1.3.2.

1.2.3 Research on New Animation Systems

The increased capabilities of our TV displays, as well as the Minsky display, has recently led to a flurry of research on extensions to Logo to provide more flexible and powerful animation facilities. Two rather different prototype systems were implemented by H. Lieberman and D. Hillis. This work also leads directly to ideas about new computer languages (Section 1.3.2) and we expect it to be actively pursued in 1975-76.

1.2.4 Developing a Design for a New Computer

We have become convinced that the time is now ripe for designing a small but very powerful computer for educational use. Under Professor Minsky's direction, several rounds of design have been undertaken. A goal for 1975-1976 is to bring these designs to fruition in the form of a working model of a personal student computer.

1.3 Research on Computer Languages

1.3.1 Logo Subsystems

One of the most important syntactic differences between Logo and more commonly used languages like BASIC and FORTRAN is that Logo is an extensible language. In other words, invoking a user-defined procedure is syntactically identical to invoking a system primitive. This makes it possible for the classroom teacher to substantially modify the way Logo "appears to the children," or to develop special purpose subsystems without having to get involved with systems programming. We have experimented with this facility in a number of different ways:

1.3.1.1 The Teach System

C. Solomon has developed a subsystem called Teach and has extensively tested it in classroom use. When this is in operation the beginner is prompted by the computer in the process of defining a new procedure. Problems of supplying line numbers and filing the procedure away when it is defined are automatically taken care of by the system. These, and other features, relieve a nervous beginning student of the burden of ideas which are not on the main line, towards the moment when he can write his own procedure and see it run.

1.3.1.2 The Fastr System

Another introductory environment for students at an even more elementary level was designed, implemented and extensively tested by P. Goldenberg. This is the Fastr (fast turtle) system. When it is in operation, merely pressing the "f" key on the teletype, for example, will cause the turtle to move forward. After a drawing has been made in this "etch-a-sketch mode," the sequence of commands is automatically defined as a procedure which can then be used as a module in constructing more complex drawing. This system proved highly successful as an introduction to Logo for very young children.

1.3.1.3 Pattern Matching

K. Kahn, one of our graduate students, implemented a sub system incorporating into Logo modern computational ideas about pattern matching and generation. He then used this in teaching children and expanded upon previous Logo work with sentence generators and other linguistic processing.

1.3.1.4 Parallel Processing

A parallel processing sub system was designed by H. Abelson and implemented by a graduate assistant, G. Clemenson. This was used in providing undergraduate math students with an introduction to the theory of Differential Games (See Section 2.1.6.).

1.3.2 Developing Ideas for a New Computer Language

When Logo was first proposed almost ten years ago it represented an attempt to build a language which would be suitable for children and also have powerful features of the advanced languages of that period. In the meantime the advanced languages have forged ahead and developed many features which would add to the power of a beginner's language. We have always thought of Logo as a growing entity which has gradually evolved since its first conception. But not all changes can be made in this local way, and we feel that the time has come to put a major effort into exploring new approaches to programming languages for education.

It might be felt that this approach is out of touch with reality. Since Logo did not succeed in displacing BASIC as the almost universal computer language for schools, surely introducing an even more advanced language is a foolish notion! This may be true, and we do not suggest putting all the eggs in the one basket of new languages. On the other hand there are objective reasons for the fact that BASIC remains entrenched, and some of these are now beginning to vanish. Among these reasons are:

the economics of computers which in the past placed a premium on a language which could exist in a small memory

the lack of convincing demonstrations of what could be done with a more powerful language

the technical difficulty of implementing new languages.

Everyone will agree that the first of these reasons is quickly vanishing. The second reason would soon dissipate if we and others (such as the Xerox group) made available in a suitable form what we now know. And the third we see as being rapidly changed by advances in software generation.

During 1974-75 we investigated new languages for education from the following viewpoints:

1.3.2.1 Intelligent Monitors

These are systems which provide direct intelligent help to the programmer in planning, defining, executing and debugging procedures. It is clear that any system which does this must have knowledge about the domain for which the programs are written as well as about the programming process itself. Work in this area was initiated by I. Goldstein in his doctoral dissertation (1973) and continued this year by M. Miller in an M.S. thesis and by M. Jeffrey in a B.S. thesis. In 1975-1976, we plan to reach an important milestone in the development of these ideas by implementing an operational monitor on the PDP-10 in Lisp-Logo. This will serve as an experimental system in which to actually observe the advantages and disadvantages for children of a learning environment in which the computer assumes many of the responsibilities of the teacher.

1.3.2.2 Actor Semantics

This new approach to the foundations of programming languages is under active development by both the Xerox group and by C. Hewitt here at MIT. Such languages seem particularly appropriate for control of animated graphics and, in this capacity, were explored in a paper by D. Hillis and in prototype systems by K. Kahn and R. Perlman.

1.3.2.3 Linguistic Implications of a Graphics-Based System

Almost all existing computer languages are designed to be used with teletypes. They do not take advantage of the capabilities for immediate visual feedback and more flexible structure which become possible with a graphics terminal. Ideas were investigated this year in papers by R. Lebel and R. Perlman, and we expect this to be an active area for future research.

1.4 Bridge Activities

The concept of "bridge activity" has evolved in our thinking to focus on the idea of creating activities, language, frames of reference, etc. which connect both to the computer experience and to the familiar informal experiences of the child.

1.4.1 Physical Skills

Our most well-developed example of bridge activities is the task of learning physical skills by conceptualizing the learning process of "people procedures" by an analogy with "computer procedures." In the past, we have experimented with projects based upon learning to ride a Bongo Board, juggling, riding a bicycle, walking on stilts and riding a unicyle. During the past year, H. Austin has developed a more precise procedural description of juggling through the use of video tapes of subjects of varying degrees of competence and at various stages in the learning process.

1.4.2 Crafts

Another area which should prove profitable n providing links between a child's normal experiences and the computer realm is that of craft projects. During the last year, Claudette Bradley has explored the craft of beading as a medium for teaching mathematical concepts. In the new Learning Lab (Section 3.3), we plan to set aside space for such activities as block printing and building mobiles.

1.5 Goals for 1975-76

The computer devices mentioned above will be used extensively with children in our new learning laboratory (see Section 3.3) during the coming months. In addition we will be starting work on a number of new devices. One is an "airplane seat" that can be interfaced to the computer for flight simulation. Another is a speech generator, which can be programmed to speak a number of different languages as well as provide voice output for Logo programs. Others include a computer-controlled tone generator which will be used to more thoroughly integrate our work in music with our work in mathematics and physics, and an organ keyboard which can be used as an input device.

Development of our time sharing system will be limited to interfacing these devices to the computer. We will also be taking advantage of the system's capabilities for filing and multiple jobs, to improve upon the Logo subsystems already developed. For example, the Teach system will be modified to make use of the new "real time" editor and a stock of "library routines" will be furnished.

We will be trying out a number of different graphics systems over the coming year, in order to find better ways to make use of color, shaded drawings and faster animation. In addition we plan to interface a tablet to the system in order to allow for graphics input. The deeper questions mentioned above, such as actor semantics, intelligent monitors and truly graphics-based languages, will be tentatively explored in implementations on the PDP-10 and will form the basis for an advanced seminar at MIT in the spring.

2. The Theory behind the Environments

Logo research in designing new learning environments has always grown from two intellectual sources: the first is the application of advanced computer technology to education and the second is an evolving theory of knowledge and intelligence based on a computational paradigm. The study of this theory is called Artificial Intelligence though this title is something of a misnomer. While it reflects the historical origins of the field in using machines as a laboratory for testing theories of intelligence, it fails to indicate that the study is essentially "theoretical psychology," i.e. the construction of possible theories of intelligence.

Logo research seeks to adapt those theories of intelligence that are suitable for people as guidelines for the design of education. This has consequences for the discovery of fundamental characteristics of learning as well as the specific organization of a subject to optimize learning.

The reader is referred to a recent paper entitled "Artificial Intelligence, Language and Education" by Papert, Goldstein and Minsky for a deeper study of these questions. A continuing goal for 1975-1976 is to extend our understanding of learning and intelligence from an AI standpoint in order to develop new educational insights and applications.

The following subsections describe specific curriculum areas where we have made progress in reformulating the content to assume a more active computational form.

2.1 Mathematics

In 1974-75 we continued our search for ways to make mathematics more intuitively accessible to young students. Progress was achieved both by examining the implications of new computer-controlled devices as well as by taking a deeper look at some of our previous work.

2.1.1 Turtle Geometry and Differential Geometry

In our proposal we outlined some theorems in our newly developed subject of Turtle Geometry. One very important one is the "Total Turtle Trip Theorem:" if the turtle follows a program and ends up in the same position from which it started, then, during the program, the turtle's heading changes by a multiple of 360 degrees. This theorem is true in the plane, but it would be false if the turtle were moving, say, on the surface of a sphere. This observation provides the basis for an intuitive Turtle Geometry approach to modern Differential Geometry--curvature, geodesics, spherical geometry, the Gauss-Bonnet Theorem, and so on. H. Abelson and A. diSessa presented this material this summer in a series of lectures for high-school students. (A paper by diSessa, which gives an extensive treatment of this topic, currently exists in draft form and will shortly be completed.)

2.1.2 "Eye Turtle Navigation" and Coordinate Systems

Consider the following project. The eye turtle is placed in a rectangular room. There is a light at each corner of the room. The turtle "notices where it is" by measuring the observed angles between the lights. Now we move the turtle to another spot. How can the turtle find its way back to the original position?

There are two very different ways to approach this problem. One is via trigonometry and standard triangulation techniques to transform the angle data into Cartesian coordinates. Another way to proceed goes something like this: "Look, there is nothing sacred about Descartes' coordinate system. Why can't I make up a better one more suited to the problem? How about using *the angles themselves* as coordinates?" This was explored by a number of students, including a high school class run by N. Rowe; also, two graduate students at the Lab, J. Galkowski and D. Taenzer, developed feedback algorithms for navigating in the "angle coordinate system" which are suitably elementary for presentation to children.

2.1.3 Signal Processing, Functions and Operators

In our work with the eye turtle, however, it became clear that a much more exciting way to use this device was to work with a 360 degree radar-like scan of the turtle's surroundings. This prompted the design of a second-generation eye turtle which is now almost completed, and we expect this to lead to many new projects. For example, the data read in by the eye is "noisy," and the signal must be *smoothed*. In looking for objects we are probably more interested in gradients than in intensities -- the signal must be *differentiated*. We think that such projects will provide very concrete and accessible images for functions and operations on functions and we plan to begin work on this as soon as the new turtle is ready.

2.1.4 Plotters and Pattern Recognition

Mounting a photo-diode in place of the pen on one of our plotters proved a convenient way for children to try their hands at pattern recognition techniques. The diode is moved using the normal plotter commands, but instead of drawing a line, the student can ask if the "pen" is currently on a light or dark area or whether it crossed a line during its last move. Some of the projects undertaken by a group of high school students were developing programs to follow along lines and curves, distinguishing between various figures, and "reading" handwritten Morse code.

2.1.5 "Germland" and Geometry on a Grid

A very different approach to geometry was further explored by I. Goldstein in "Germland," a subsystem of Lisp-Logo. Unlike turtles, "germs" live on a grid and when they move they can only move north, south, east or west. But there can be lots of germs all moving at once, foraging for food or chasing one another. This forms a background for a number of projects merging ideas from ecology, game theory and automata theory, and we will continue development here.

2.1.6 Differential Games and Parallel Processing

One outgrowth of the germland idea was a PDP11/Logo subsystem for parallel processing. This was used by a class of MIT freshmen to investigate problems in the theory of differential games. They wrote Logo programs to test various "chase-evade" strategies, explored the classical "lion and man" problem and the "ABM missile" problem.

2.1.7 Turtle Geometry and Number Theory

Almost everyone exposed to Turtle Geometry quickly invents the "Poly" program illustrated in our proposal. But let's explore Poly: What is needed to make the program draw a five-sided figure, a nine-pointed star? How many points will there be if we use a 50 degree angle? What happens when we begin to modify the program? Starting from questions like these we soon find ourselves in new mathematical territory, a subject combining geometry, number theory and theory of computation. Questions range from being suitable for children to forming bases for ambitious projects at the college level. These were discussed this year in a working paper by H.

Abelson.

2.2 Physics

2.2.1 Orbits

The theory of planetary orbits outlined in our proposal was extended by H. Abelson, A. diSessa and L. Rudolph into a complete introduction to this subject, including a qualitative approach to first order perturbation theory. This was published in the July 1975 issue of *The American Journal of Physics* and also provided the theoretical background for an orbit simulation program discussed below (Section 2.5.1).

2.2.2 Color

We are anxiously awaiting the installation of our new projecting color TV console during the coming month. Anticipated projects will deal with color mixing, spectral theory and optical illusions involving color vision.

2.2.3 Sound

Our proposed work in spectral theory should also dovetail nicely with projects in the generation of sounds. This will also be linked with work in music as well as with echolocation projects mentioned above (Section 1.1.2).

2.2.4 Qualitative Physics

The above work has sparked a general interest in what might be called the theory of "qualitative physics." This involves investigating knowledge used in solving physics problems, beyond what is classically formulated in equations. Specific projects last year included a completed M.S. Thesis, "Qualitative and Quantitative Knowledge in Classical Mechanics" by J. deKleer, and some preliminary work by H. Lin on problems in understanding thermodynamics.

2.3 Biology

2.3.1 Tropisms

The sketch on tropisms outlined in the proposal was extended by H. Abelson in work with MIT freshmen. This was another factor in the development of the parallel-processing system mentioned above (Section 2.1.6).

2.3.2 Logomecia

Thinking about tropisms also led to work on the theory of "Logomecia," a combination of biological considerations about tropisms and kineses with more mathematical notions of feedback and scalar and vector fields. S. Papert and C. Solomon did work in this area with children at the Martin Luther King chool in Cambridge.

2.3.3 Morphology

Improved graphics and animation facilities in 1974-1975 stimulated work on procedural insights into the shapes and movements of living things. A program developed by B. Dalzell demonstrated how simple mechanisms could account for the evolution of animal horns. Dalzell and H. Lieberman have also begun work on a simulated "build-an-animal-kit." This allows students to assemble new animals out of pre-programmed modules such as the head of a carnivore, the body of an herbivore, various legs, tails and so on. The program has not yet been tested with children, and we are particularly anxious to do so during the coming year. We also plan to provide for animating the figures, as well as developing theoretical material to accompany the program. Why, for example, does an animal with a carnivore's body and an herbivore's head "look funny?" How could such a creature have evolved?

2.4 Music

2.4.1 Insights into the Learning Process

The work of the music group took a major leap forward this year by establishing a small satellite lab in a local public school. Telephone, computer terminal and music box together with a variety of drums, bells and other instruments were moved into a room provided by the Martin Luther King School in Cambridge. There, J. Bamberger and G. Greenberg, a graduate assistant, worked with 4 nine-year-olds (and about 8 insistent visiting children) who were turned loose on our new materials, new languages and new games. The new content grew out of the previous year's rethinking of the subject matter, its implications for general intellectual development and its interfaces with the larger Logo world.

A detailed documentation of this experience has proven extraordinarily rich in revealing individual differences between children and ways in which known cognitive structures come into quite unexpected interactions. One out of many hypotheses to account for the richness of events in this experiment is that music is "out of step" with the general cognitive development of the children so that the learning process is able to take a form analogous to crystallization from a supersaturated solution. Whatever the reason, there is no doubt that this learning situation is extremely interesting as much (or more!) from the point of view of intellectual development in general as from the narrower point of view of music education.

2.4.2 Representing Musical Events

G. Greenberg has developed a visual display for music which includes a variety of ways for picturing pitch and time; each of the pictures captures different features and relations of the musical structure, sound and picture are generated simultaneously. Next year we hope to implement the possibility for a child to actually perform on a drum or keyboard as input to the computer, i.e., performance will generate a real-time display of both picture and sound which will remain in computer memory. A mechanical "time machine" which gives the child more "hands on" control of the whole process has already been built. We also want to integrate music and turtle animation to show relations between visual and sound transformation processes.

In another area D. Johnstone, an MIT graduate student, has been developing formal models of children's individual strategies for processing simple rhythms. Using the experimental results of Bamberger's work with children, Johnstone is developing the Logo music language to make it more compatible with intuitive representations. At the same time he is working on projects and games which include powerful tools for procedural music-thinking; this kind of procedural thinking extrapolates to building structures in other domains, as well.

Finally, our "center" in the Education Division has attracted a number of MIT undergraduates through a course (Experimental Studies in Musical Perception and Learning) which pushed the potential of the Logo music system and its underlying thinking well beyond their previous limits. Students observed their own and others' cognitive strategies in musical problem solving (see the paper, "What's in a Tune") and also composed rather complex pieces using entirely procedural descriptions of the structural relations they wanted. Their copious papers on these various projects will be compiled and summarized in a forthcoming article.

2.5 Games and Simulations

2.5.1 Orbit System

The material on planetary orbits (see Section 2.2.1) led to a Logo subsystem and a number of games and simulations dealing with orbital mechanics. These were designed and implemented by A. diSessa, who will present a descriptive paper in September at the IFIP Second World Conference on Computers in Education. We feel that this work is rather unique in that it embodies not only an interactive and extensible system for exploring physics, but also builds upon a *theoretically different* way of presenting this material.

2.5.2 Dazzle Dart

Everyone who knows the computer world knows the game spacewar. Few games rival spacewar in its ability to hold players in a state of deep concentration and to develop such a complex culture of expertise. We would like to harness such games for educational use. The question arises whether Spacewar is in some way unique in terms of its fascination for the player.

Last fall, H. Abelson, A. diSessa and N. Goodman undertook the goal of designing a new computer game that might rival spacewar in popularity. They succeeded and created a game called Dazzle Dart. This is a team game similar to hockey. Instead of hitting a puck, the attacking team tries to shine a "beam of light" into a goal. The players control movable mirrors which are used to deflect the beam. The rules require teammates to score, not by "direct hits," but by setting up reflection patterns among all the players. During January 1974 the highly successful "First World Dazzle Dart Competition" was held at MIT.

While this is merely a "frivolous game," we see it as a compelling confirmation that the use of computers for highly interactive real-time control represents a potentially rich area which has hardly been touched by educational researchers.

2.6 Language

Theoretical work on the relations between Artificial Intelligence, linguistic studies and education have become a major theme of work in the MIT Artificial Intelligence Laboratory and in other centers. Several faculty members and graduate students here are developing new projects using computers to increase or observe the linguistic abilities of children. Under a separate National Institute of Education grant, Professors Papert, Goldstein and Minsky completed a survey of recent progress in Artificial Intelligence theories of language and studied their possible application to education. In addition, Professor H. Sinclair of the University of Geneva will be spending the fall term with us as Visiting Professor in the Division for Study and Research in

Education, and we expect the theoretical basis for our work in language to be significantly enhanced through this interaction.

2.7 Goals for 1975-76

Our energies during this coming year will be devoted towards thoroughly integrating this new content material into our teaching experiments. We expect to see a number of joint physics-music projects centered around sound generation, a great deal of work with the new color display, and more investigation of "germland-like" introductions to geometry. The simulated "build an animal kit" will be expanded and interfaced with a tablet in order to allow children to create their own "animal parts." Work on animating these creatures will point the way towards an elementary "procedural biophysics" (How would you design a sturdy, yet flexible, leg?) as well as complement our current material on tropisms.

We plan to continue our work in language along two dimensions. The first is to develop curriculum units for the various natural language projects which we have explored in the past, including the design of simple question-answering programs, sentence generators and parsers. The second is to utilize advanced language comprehension systems developed by A.I. as interfaces to the intelligent monitor (Section 1.3.2.1) that we plan to implement during the coming year. We will also interface Logo language projects with a voice generating device. The sophistication and relative economy of such devices make them an obvious additional medium in which children can explore language (beyond simply teletype interactions).

3. Experimenting with Learning Environments

3.1 Overview of Teaching, 1974-75

About 35 children ranging in age from 6 to 11 spent some time in the Logo world this year. Their work was supervised by 8 people, including graduate and undergraduate students, Logo staff and faculty. Most of the children came form the Martin Luther King and Cambridge Alternative public schools. They worked in temporary facilities in the Logo lab except for those who were in a satellite lab with the King School (Section 2.4.1). The children dealt mostly with turtle geometry, and this year our staff developed new ideas for teaching, for giving children more flexibility and for individualizing instruction.

Staff members P. Goldenberg and C. Solomon invented a number of procedures which are "child-sensitive" in that they relieve beginners of many of the often frustrating details of programming (See Sections 1.3.1.2-3.). The fourth and fifth graders became quite adept at manipulating the basic turtle commands, and did animation projects which had embedded in them the paradigmatic heuristic of debugging, editing, subprocedures, and dealing with inputs and variables.

We have already mentioned some of the new devices (Section 1.1.5) and new computer systems (Sections 1.3.1) that were motivated by our work with pre-schoolers through third grade students. But hardware and software alone are not sufficient to make the computer environment accessible or beneficial to young children. E. Hildreth, an undergraduate at the lab, is preparing a booklet called "Logo for First and Second Graders: A Teacher's Helper" which is rich in new ways of approaching turtle graphics, suggests both basic problems and basic new knowledge that children acquire in developing projects and also provides a detailed discussion of "bridging activities" between computer concepts and the children's everyday world.

Techniques for teaching first and second graders can also be profitably used in work with older children, as well. For example, a fifth grade child might spend half an hour working through what might be the entire program for a first grader. But even this brief initial period seems to have a substantial effect for some of the children, particularly the "unmathematical" children to whom we have always given special attention.

3.2 Interactions with Piagetian Psychology

The Genevan School of genetic epistemology is an important intellectual source for our point of view. Our project is now at a level of development at which it is able to give as well as take from Piagetian thinking. Last fall Logo and the Education Division cooperated in inviting two students from Piaget's center, O. de Marcellus and E. Ackermann, to spend a month with us. Accompanied by S. Papert, C. Solomon and a number of MIT students, Marcellus and Ackermann made daily visits to Cambridge elementary schools where in the Piagetian style, they observed and interviewed young children and made videotapes of their experiments. The results of these, as well as broader issues of developmental psychology, were discussed by the group in a weekly seminar.

S. Wagner, a graduate student at Harvard who has also studied at Geneva, is currently interviewing children in Cambridge nursery schools in order to plumb the nature of their "linguistic theories:" what's a word; what's a sentence; how do you know? He has also been teaching Logo to 8 and 9 year-olds with a special eye toward projects which will involve the children specifically in talking about these things.

Interactions with the Center for Genetic Epistemology in Geneva (Switzerland) will continue during 1975-76 under joint sponsorship with the Education Division. Two students from the Center, C. Damni and C. Othenin-Girard, will again be collaborating with us in the fall, and H. Sinclair, Professor of Psycholinguistics at the University of Geneva, will be a Visiting Professor at the Education Division.

3.3 The New Learning Laboratory

The lack of adequate non-computer materials and a flexible environment in which children could take naps or play actively has hampered our teaching experiments over the past two years. During this time we have been continually pressing to establish a larger and better designed learning environment on the MIT campus. The construction of such an environment is now underway and should be completed by late September.

Beginning as soon as possible (October 1) groups of children aged 7 through 15 will come to the lab on a regular basis. We have an on-going contact with teachers and administrators in local schools. We have invited them to come with their children to observe and work, to attend the series of lectures which will initiate our own students into work in the lab and to keep a running "dialog" about how their work in the classroom can interact with our work in the lab.

The lab will include computer display terminals, a music room, a room for physical skills, spaces for devices that are interfaced to the computer (eye-turtle, electric train, airplane seat, etc.) and areas for non-computer "bridge" activities such as block printing and building mobiles. This will be a major step towards having our own learning environment and creating the opportunity for children to be much more independent in choosing their activities and developing long-term projects. In addition it provides a real area for observation, for designing and implementing new projects and for teacher training.

Work in the new learning lab will be a major focus of activity during the coming year. We hope that by the spring semester approximately thirty hours per week can be devoted to work with children from local elementary schools. During this final year of our 3-year contract, we shall particularly concentrate on refining both our computer material and our presentation. We shall also pay particular attention to non-computer "bridge" activities such as those mentioned in Section 3.1. In addition, teaching activities in the lab will be an integral part of several MIT courses to be taught during the coming year (see Section 4.8).

3.4 Work with Older Students

We also worked with high school students and college undergraduates in the Logo environment during 1974-75. This is not the major focus of our teaching activity, but it has nevertheless proved to be a valuable complement to our teaching at the elementary level. It is often possible, for example, to test preliminary versions of projects for children by using them with older students.

3.4.1 High School Students

Teaching high school students was done in the summer of 1974 under the auspices of the MIT High School Studies Program in classes led by J. Evans and N. Rowe. This summer R. Fischer, himself a student introduced to Logo in Rowe's class, ran an HSSP program. These classes were used to test devices like the light turtle (Section 1.1.1) and the plotter (Section 1.1.6); also, Fischer's class has been experimenting with language and pattern matching (Section 1.3.1.3).

There is another small group of high school students who have been using Logo on an informal basis throughout the year. They have turned their attention to computer games, and using our Logo system, have been able to design, implement and improve upon games such as "ping pong" and "moon lander" which are normally only *used* by students and developed by computer professionals.

3.4.2 College Undergraduates

We also experimented this year using Logo as a tool in MIT undergraduate courses. (Courses *about* the Logo project are discussed in Section 4.1.)

3.4.2.1 Mathematics

For the past two years, H. Abelson has taught seminars centered around use of the Logo system to MIT mathematics students. In 1975 the classes concentrated on *doing* mathematics as opposed to *learning about* mathematics. This was accomplished through Logo computer projects which, although simple from the purely programming point of view, lead quickly and naturally to questions for mathematical research. The approach allowed even beginning undergraduates to work as creative mathematicians without having to first master a formidable technical apparatus. We expect to repeat this course in 1976, and A. diSessa plans a similar experiment in physics.

3.4.2.2 Music

J. Bamberger led a seminar in which undergraduates used the Logo system in order to focus on such questions as: what does it mean to *understand* a piece of music? What is *intelligent musical behavior*? How does it develop? How does it relate to other aspects of intelligence? Undergraduates observed each other in various musical problem-solving activities, formulated hypotheses about how the features of a piece generate musical coherence and tested these via Logo and the music box.

3.4.2.3 Computation in the Undergraduate Curriculum

Although our work focuses on elementary school science, we believe that the kinds of ideas we have been developing are equally germane to education at the undergraduate level, and that the concentration on "computer-based dialogues" is as limited and short-sighted in the university as it is in the primary school. This year we began discussions in this area with other educators at MIT, and alternative uses of computation in the undergraduate curriculum are discussed in a paper in progress by H. Abelson.

3.5 Experiments in Learning

3.5.1 Thermodynamics Seminar

During spring 1975, S. Papert ran a seminar with the goal of understanding why a subject like thermodynamics is universally considered to be among the most difficult of the undergraduate science curriculum. Could a reformulation of the subject from a procedural viewpoint decrease its difficulty for a student? This examination of thermodynamics is still underway and represents one of our goals for 1975-1976. However, it is worth mentioning here the method involved in this enterprise, namely actually studying the subject in a meta-student mode.

The "meta" refers to a concern in not only solving the problems traditionally posed in textbooks, but to describe, classify and discuss the problem solving strategies used. This approach complements nicely the design of learning environments and we plan to apply it to other subjects in the coming year.

3.5.2 Informal Thinking Seminar

The DSRE sponsored a course given jointly by S. Papert, B. Snyder, D. Schon and S. Rosenberg which studied the nature of "informal thinking," as opposed to formal scientific problem solving. Again the technique was for members of the seminar to study some new problem in "meta-student" mode. Typical of the kinds of projects which students undertook were to learn to sketch, to learn how to describe to another the process of untying knots or to learn to juggle. There is a common core to Informal and Formal Thinking in terms of problem solving, planning and debugging techniques. During 1975-1976, the course will be given again with the goal of making further progress in understanding informal thinking and developing techniques for "thinking aloud."

3.6 Goals for 1975-76

We conclude with a more detailed presentation of our teaching plans for the coming year. Our objectives fall into four broad categories:

A. Improving our presentation of Logo ideas. Developing and comparing different approaches to work in Logo.

B. Obtaining clearer and more reliable observations of children at work in the Logo environment. Being more precise about the skills which children learn through Logo activities.

C. Using computational tools and ideas in cognitive research.

D. Building an intellectual community. Clarifying prerequisite skills for doing this kind of research. Investigating issues of teacher training.

The following nine teaching activities are listed to give examples of specific ways that we plan to meet the above objectives in the coming year. The list is only representative and is not intended to be comprehensive. It does not, for example, include anticipated continuations of our work at the high school and undergraduate levels, nor the further development of computer devices and new curricula discussed in our progress report.

3.6.1 Developing a Better Vocabulary for Planning and Debugging

Formulating plans and debugging programs have always been two essential components of a child's Logo experience. But in our teaching, we ourselves have not been very precise about how one goes about doing these things. Recent research in artificial intelligence has developed a rich vocabulary for describing various types of planning and debugging strategies. One of our classes will focus on issues of planning, and especially attempt to have children become more articulate about their plans and planning strategies.

3.6.2 "Geometry on a Grid" as an Alternative Introduction to Logo

Most children introduced to Logo have begun with turtle geometry, drawing pictures and animating them. One of our classes this year will start with "germland" type programs as an introduction to Logo. This will involve a different set of mathematical concepts. For example, the notion of "angle" hardly appears at all, but issues concerning interacting programs come immediately to the forefront. How does this compare with turtle geometry as a source of projects for children? What new kinds of bugs arise? How does this alternative introduction to Logo affect the kinds of complexities children can deal with in projects?

3.6.3 Animal Behavior

Another class will be exposed to yet a different alternate introduction to Logo, based on procedural models of animal behavior. Questions here will be similar to the ones listed under (3.6.2) above.

3.6.4 String Figures

G. Freuder and G. Iba plan to investigate the use of "sculpturing figures out of string" (symmography) as a bridge activity. They will develop a procedural vocabulary for explaining this craft to children and also have the children participate in coordinated computer activities. (For example, using the computer as a design aid to simulate various possible string figures.) We also expect to focus on issues of how the children move back and forth between the "abstractness" of the computer simulation and the "reality" of the actual materials.

3.6.5 Modifying Procedures and "Systematic Changes"

This activity addresses more directly issues of how Logo work helps develop the capacity for "formal thinking". Children will be asked to focus on the relations between the changes they make in their procedures and the changes in "what the procedure does", to talk explicitly about what changes and what remains invariant, and to find strategies for making systematic changes. (For example, draw a necklace with round beads on the display. Now modify the procedures to make every other bead square.) This will be coupled with more classical Piagetian experiments dealing with similar issues.

3.6.6 Frames of Reference

This is another investigation into a component of "formal thinking" which will be coupled with piagetian experiments. Children will be given access to Logo environment which encourages them to explore frames of reference and relative motion.

3.6.7 A Psychology Lab for Kids

A class of children will be taught to write simple Logo programs which illustrate psychological experiments. (For example, drawing the Muller-Lyer Illusion on the display or generating and testing for recall of strings of numbers.)

3.6.8 Assembling Pictures out of Parts

In a series of experiments to be conducted by S. Wagner, children will be given access to programs which draw various standardized geometric shapes. They will then be asked to assemble these into specific pictures and discuss which parts are necessary for constructing a given picture.