1. [illegible] GENERAL TURTLE

The Incorporation of GENERAL TURTLE Inc. in 1972 was motivated by the following propositions:

A DEMAND: The educational use of computers has become widely accepted and has created a substantial market for materials, technologies and ideas to support and enhance this application of computers.

A SUPPLY: A new generation of educational uses of the computer has been incubating during the past five years in a few research laboratories and experimental teaching projects. GENERAL TURTLE's founding principals include leaders of this research and development work, particularly Marvin Minsky and Seymour Papert, both professors at M.I.T. Thus, GENERAL TURTLE is in a very strong position to bring a supply of new methods to meet the growing demands for them.

WEAKNESS OF COMPETITION: The design of the computer devices currently used in schools and colleges has been dominated by the giant computer corporations which are neither fitted by competition and tradition nor very eager to play an innovative role in education. In fact, their policy has been to transfer into the schools, systems, terminals, and programming languages designed for other uses in industry and commerce.

A PRODUCT: By contrast, GENERAL TURTLE's first product is an engineered version of a computer peripheral designed specifically for educational purposes and developed over a period of five years of testing and improvements in experimental classes under the direction of Minsky, Papert and their collegues (this product, known as a TURTLE LAB is described in a later section).

OUR NAME: The name of the corporation comes from the use of the word "TURTLE" as a generic term for robotic devices which can be programmed by children to simulate behaviors of real animals, to draw geometric designs, to exercise strategies in mazes or obstacle courses, to make noises and so on in endless variety. The educational value of such super-toys comes from the fact that they draw the child into exercising mathematical, logical and scientific skills in the pursuit of activities which are intensely interesting in their own right. GENERAL TURTLE's product line already goes beyond "TURTLES"; but the concept of the TURTLE typifies the new uses of computers as educational devices capable of providing greater opportunities to learn in an active, involved way.

AMBITIONS:

ULTIMATE: GENERAL TURTLE is taking the initiative in a field which will eventually grow into a multi-billion dollar sector of industry. If GENERAL TURTLE can hold this initiative, it has almost unlimited potential for growth.

IMMEDIATE: For the immediate future GENERAL TURTLE's goal is to establish a position as the supplier of advanced equipment to upgrade traditional computer installations in those forward looking schools and colleges which have made an early commitment to the educational uses of computers.

2. Record.

Develop a Product Range.

The first product chosen was a modular set of devices known as a TURTLE LAB. These devices had all been previously developed sufficiently for use in experimental classes in public schools as part of an M.I.T. project. It was necessary to turn them into a more robust, easier-to-operate form. This developmental work occupied most of the first year. By the end of 1973 a small first batch of TURTLE LABS had been manufactured and delivered to users. A standard TURTLE LAB costs in the vicinity of $3,000 (the exact amount depending on the choice of options.) It is used to increase the value of an existing computer installation by extending the range of actions that can be carried out under computer control. Most computer installations in school settings are in fact very tightly limited in what they can do: generally the effect of a computer program written by a student is to type numbers or other messages at a Teletype terminal. The TURTLE LAB enables the computer to generate music, turn motors, draw pictures and diagrams. These extended actions enrich the computer experience for the student by making it more realistic, more closely related to other school subjects and realworld applications and more personally exciting. Moreover, these extra benefits are obtained at lower cost, since the student, being more involved, learns very significantly faster!

TECHNICAL.

In the early part of 1974, the decision had to be made- to use the limited resources of the company to market the TURTLE LAB as it then was or to develop a wider range in the field of GRAPHICS which was becoming more and more popular in M.I.T. and in the computer user's market at large. It was decided that NOW was the time to introduce SUPER-GRAPHICS at a reasonable price and that, if the development was delayed, the initiative would be lost. All but a small part of the resources available were applied to this project which went through a prototype phase in the summer of 1974 and has reached pre-production stage in April 1975 in the form of the TT 2500 GRAPHICS TERMINAL, described later.

PRODUCTION:

The actual manufacture of the version for the TURTLE LAB was sub-contracted to THORNTON ASSOCIATES in order to keep our initial capital investment as low as possible. New modules for TURTLE LAB options are now being made directly by GENERAL TURTLE. The TT 2500 will be manufactured by subcontracting piece parts and final assembly by General Turtle.

Develop An Image.

PUBLIC RELATIONS:

GENERAL TURTLE has a running start in this area as well as a result of the increasing notice being taken of the TURTLE concept and Seymour Papert's work on new educational methods.
The attractiveness of these concepts to a wide range of audiences is very visible from the press coverage they have received.
Notice has been taken of them during the past year by:

NEWSWEEK... on which no comment is necessary.

THE MATHEMATICS TEACHER...this professional journal of teachers of mathematics described the TURTLE LAB as "revolutionary... both the products and ideas that motivate them may indeed revolutionize the pedagogy of mathematics fundamentally".

SATURDAY REVIEW... in a special feature on technology in education, GENERAL TURTLE was given a full page.

SCIENCE NEWS... "By learning to program the computer to generate music, pictures or mechanical processes, the student develops the mental tools to think about temporal, tonal, geometric and physical matters."

NATURE...this prestigious and sober British science magazine states "children can thus gain an understanding of notions such as length and angle....variable, vector state...and in doing so make discoveries about the meaning and power of these ideas.

LEARNING MAGAZINE...in a four-page article "...it introduces them to one of the most powerful heuristics (tools for learning-about-learning) of all intellectual life."

During the year GENERAL TURTLE developed its public relations through a number of channels:

- Publication of the first number of a series entitled "New Educational Technology"
- Presence at meetings and conventions
- Personal relations with leaders in the field of education technology.
- Loans of demonstration equipment
- And above all, careful attention to the mood and interests of many categories of people and interests

In the intitial period the sales policy had two prongs: <u>concentration on effecting sales to a select clientele of prestigious and visible users</u> while at the same time <u>preparing the way for broaching the larger, general market</u>. The result of the first prong is visible in the list (Section (6)) of institutions at which TURTLE LABS have been installed (some purchased, some leased with intention to purchase, a few loaned as part of a deliberate public relation policy.)
While GENERAL TURTLE intends building up its own sales force, it is working through agents in the U.S.A., Canada, Germany and Sweden.

TECHNICAL PLANNING:

The success of GENERAL TURTLE depends on its ability to maintain initiative in a growing technical area. It would be disastrous to concentrate entirely on our initial product and we have, in fact, devoted as much energy to preparing for new products and for updated versions of the existing one. Doing this in an orderly fashion has the important consequence that we can always design our products so as to be compatible with the next round (see below for descriptions of new products now under development.)

FINANCIAL:

Funding sufficient to achieve the above initial objectives was provided by NOIL ESTABLISHMENT of Lichtenstein and the private stockholders of GENERAL TURTLE. See Section 6 for details of expenditure.

Additional funding is now being sought as detailed in Section 8

COMPANY NAME:

In February, 1975, GENERAL TURTLE INC. was merged into GENERAL TURTLE DEVELOPMENT CORPORATION. The company is referred to in this plan as GENERAL TURTLE.

3. Products - and new Products.

TT 2500: A revolutionary Graphics Terminal which, although specifically designed for TURTLE learning applications, is being enthusiastically received by users in many areas. A bread-board prototype, produced in the summer of 1974, is being used to generate advance orders for the TT 2500 particularly in Canada. (See Appendix for details of the device.)

TURTLE LAB CONTROLLER: Provides a cheap, easy-to-use method of connecting up to four TURTLE devices to a computer.

TURTLE: This is a small computer-controlled robot or vehicle. It is driven by motors: it has touch sensors built in and provision for attaching other sensory modalities: auditory, visual etc.. It has a pen-holder so it can be used as a crude but intuitively clear plotter.

MUSICBOX: This can generate 60 pitches (5 12-tone octaves) and two drum sounds in up to four voices.

SCANNING PLOTTER: For computer drawing and for character recognition.

NEW PRODUCTS ARE INCUBATING ACTIVELY. Very nearly ready is:

CONSTRUCTION KIT: Motors, solenoids, sensor devices, relays and logic modules to allow Junior High School and older students to construct or control devices through the computer. Also valuable for research laboratories, industrial bread-boarding etc..

Products further away include:

Multiple Graphics Display Systems:

Self-contained systems for use by handicapped or very young children.

A self-contained TURTLE/LOGO Computer- a planned expansion of the TT 2500.

Integrated Computer Systems for Schools, Museums etc..

5. Personnel

Alan H. Papert - President, Director:

Alan H. Papert, B.Sc. (Eng.) C.Eng. M.I.E.E. was for ten years responsible for the design and checkout of various aspects of computer equipment within the Elliott-Automation Company now part of the British General Electric Co. Ltd. He was appointed Deputy Chief Engineer in 1965 responsible for 50 engineers and draughtsmen working on the design of computer peripherals and has since been responsible for the electronic aspects of design of a graded fare collection system for use on a bus, a $300,000 program to develop a thermal analysis system, computer packaging for airborne computers and for forward product planning within the military computer group of the British G.E.C.

Since September, 1972, when GENERAL TURTLE INC. began operating, Alan Papert has served as President, General Manager and Chief Engineer, being responsible for liaison with Thornton Associates and, directly, for the design and development of the Plotter/Scanner Controller, and the TT 2500.

MARVIN MINSKY Consultant, Director

Professor of Electrical Engineering
Co-director, Artificial Intelligence Laboratory
Massachusetts Institute of Technology

Education: Attended Fieldston School, New York; Phillips Academy, Andover; Bronx High School of Science; B.A. Harvard, 1950; Ph.D. Princeton, 1954; Junior Fellow, Harvard Society of Fellows, 1954-57.

Professional: Junior Fellow, Harvard Society of Fellows, 1954-57.
Staff Member, Lincoln Laboratory, M.I.T. 1957-58.
Assistant Professor, Mathematics, M.I.T. 1958-61.
Associate Professor, Electrical Engineering, M.I.T. 1961-64.
Professor of Electrical Engineering, M.I.T. 1964-present.
Co-director of Artificial Intelligence Laboratory, M.I.T.

Honors and Societies: Fellow, Harvard Society of Fellows.
Fellow, Institute of Electrical and Electronic Engineers.
Fellow, American Academy of Arts and Sciences.
Fellow, New York Academy of Sciences.
Radio Amateur License KIYAR.
Turing Lecturer, ACM, 1970.
Member, National Academy of Sciences.

Born in 1927, Dr. Minsky served in the U.S. Navy in 1944-45, received a B.A. from Harvard in 1950, and a Ph.D. from Princeton in 1954, writing his dissertation on a theory of learning for neural nets with loops. He was a Junior Fellow of the Harvard Society of Fellows from 1954-57, turning from neurophysiological theory towards Artificial Intelligence, and in 1957, he joined Oliver Selfridge at M.I.T.'s Lincoln Laboratory. In 1958, he joined the department of Mathematics at M.I.T., and in 1959 formed the Artificial Intelligence Project with John McCarthy. The project belonged originally to the Research Laboratory of Electronics, became a part of M.I.T.'s Project MAC in 1963, and in 1970 became an independent M.I.T. laboratory. Professor Minsky transferred to the Electrical Engineering Department in 1962. Much of his work in recent years has been in collaboration with Professor Seymour Papert of the MIT Mathematics Department..

Who's Really Who in COMPUTERS

In less than three decades the world has been radically altered by computer technology. Yet few people even know the names of the men responsible for creating the machines and systems that have transformed industrial society. Below, Newsweek International profiles seven movers and shakers in the computer revolution.

Bruno Lussato: French Revolutionary

Tunisian-born Bruno Lussato has begun to rewrite the rules of the world's computer industry by thinking small. Lussato launched his career by inventing the computer terminal now used by many banks and department stores to keep track of deposits and record sales transactions. Building on that breakthrough and on the rapid advances in miniaturization technology, the 42-year-old Frenchman has pioneered the use of the minicomputers. Lussato, in fact, believes that the whirring behemoths that the ordinary person envisages when he hears the word "computer" may soon become a relic of the past. In their place, Lussato foresees thousands of desk-top computers that will be as essential a part of the businessman's office as the typewriter is today.

An accomplished painter and pianist, Lussato turned writer recently, co-authoring "La Micro-Informatique," a book which outlines his theories on miniaturization and which has created a scientific sensation in France. Seemingly unfazed by his newfound eminence, Lussato, now a professor at the prestigious Conservatoire des Arts et Métiers in Paris, confidently predicts that in the computer industry less will be more. "The big firms do not want to admit it," he says. "But they are being forced to do so because, in fact, the most efficient computer is the smallest one."

Gene M. Amdahl: Independent Superstar

Although minicomputers have suddenly become fashionable, there still are some computer wizards who put their faith in ever more powerful computers. One of these is Dr. Gene M. Amdahl, a former IBM designer turned entrepreneur. Paradoxically enough, Amdahl, 52, owes his preeminence and prosperity to a ruptured disk. Although he had long been dissatisfied with the limits IBM put on his creativity, it was not until he spent ten months recuperating from an operation on his back that Amdahl finally mapped out mentally his plans for a brand-new, high-speed computer. The machine Amdahl hoped to build would be the first true fourth-generation product and would be designed to compete successfully with IBM's then-dominant 370 series.

Back on his feet, Amdahl quit IBM and promptly founded his own company, Amdahl Corp., a few miles south of San Francisco. Despite Amdahl's reputation as one of IBM's scientific superstars, his company had a tough time of it financially until the Chicago-based Heizer Corporation came through with $2 million in backing. Eleven months later, Fujitsu, Japan's state-backed computer firm, also decided to invest in the firm and a year later West Germany's Nixdorf Corporation followed suit.

Since then, the South Dakota-born Amdahl hasn't looked back. He has sold more than two dozen of his first computer for a total of nearly $100 million in sales and has carved out a 10 per cent share of the market against IBM. Nor does his company's relatively small size seem to have hindered Amdahl's continuing commercial battle against his former employer. This month, his company shipped its first 470/V6 model computer. The latest Amdahl creation runs identical programs to the top of IBM's 370 line and costs roughly the same (about $4 million). But Amdahl claims that his model will operate two times faster than IBM's and thus give the purchaser more bits and bites for the buck.

Marvin L. Minsky: The Friendly Genius

He is a slender, easygoing teacher who gets on well with his students and likes to work in blue jeans and turtleneck sweaters. But Marvin Minsky, 46, is more than just another affable scholar. Founder and co-director of the Massachusetts Institute of Technology's Artificial Intelligence Laboratory and holder of the school's prestigious Donner professorship, Minsky has for more than a decade pursued a singular passion: finding out how to make computers "think."

Early on, Minsky decided that much of the problem-solving potential of computers was being wasted because the machines relied on people to tell them what to do. If the programmer was unable to frame specific questions—a frequent situation when highly sophisticated research is involved—the computer couldn't function. Minsky's answer has been to let the machines do more of the work. The computer is told that whenever specific instructions are lacking it should go ahead and search for an answer in its memory banks in a high-speed trial-and-error process.

Minsky's work in artificial intelligence has spanned a variety of academic disciplines and involves the development of theories on how both living organisms and machines think, see and communicate. Somewhat ironically for a man known to his colleagues as an archetypal absent-minded professor, Minsky is currently fascinated with human memory.

Machine Age Visionaries

Don Lau

(Clockwise from the top) Amdahl, Minsky, Lussato: Dreamers and pioneers, exploring the vastnesses of an ever-expanding technological frontier

DR. SEYMOUR A. PAPERT Consultant, Director

Born: March 1, 1928 in South Africa
Citizenship: United States
Academic Position: The Cecil and Ida Green Professor of Education,
Professor of Applied Mathematics, M.I.T.

Degrees

B.A.	(Honors) University of the Witwatersrand, 1949 Mathematics and Philosophy
Ph.D.	University of the Witwatersrand, 1952 Mathematics
Ph.D.	Cambridge University, 1959 Mathematics

Professional Experience

1949-53	Lecturer in Mathematics, University of the Witwatersrand
1954-56	Research Scholar of the Royal Commission for the Exhibition of 1851; held at St. John's College, Cambridge, England
1956-57	Chercheur a l'Institut Henri Poincare, University of Paris
1958-63	Member of the Centre International d'Epistemologie Genetique at the University of Geneva (Part-time 1959-61)
1959-61	Senior Fellow, National Physical Laboratory, London, England
1962-63	Charge de Cours in Cybernetics, Faculty of Science, University of Geneva
1963-67	Research Associate, Electrical Engineering, Massachusetts Institute of Technology
1968--	Professor of Applied Mathematics, Massachusetts Institute of Technology
1967--	Co-Director, M.I.T. Artificial Intelligence Laboratory
1971-1972	Visiting Professor, Rockefeller University
1973--	Professor of Education and Applied Mathematics, Massachusetts Institute of Technology

Recent Papers on Education

"Teaching Children Thinking"
Bulletin of the Association of Teachers of Mathematics,
No. 58, Spring 1972.

Also in Proceedings of IFIPS Conference on Computers in Education, Amsterdam, 1971.

"Twenty Things to do with a Computer"
(with C. Solomon)
Educational Technology, XII, 4, April, 1972.

"Teaching Children to be Mathematicians versus Teaching about Mathematics"
Int. J. Math. Educ. Sci. Technol. 3, 249-262, 1972.

"On Making a Theorem for a Child"
Proceedings of the ACM Conference, Boston, Aug., 1972.

"A Computer Laboratory for Elementary Schools"
Computers and Automation, Vol. 21, No. 6, June, 1972.

"Teaching Children Thinking"
Programmed Learning and Educational Technology, Vol. 9, No. 5, September, 1972.

"We want to see how memory is involved in solving problems and in dealing with language and vision," he says. "We're seeking a single theory to explain all three.

Seymour A. Papert: The Zookeeper

Co-director with Marvin Minsky of MIT's Artificial Intelligence Laboratory, Seymour Papert, 46, has built his career by combining two of his greatest loves: children and computers. A bearded South African, Papert uses computers as teaching tools and has found ways to give very young students "hands-on" experience in programing computers.

Papert's work has involved the creation of computer-controlled "super toys" and dozens of cybernetic animals known as "turtles." In a departure from previous experiments with children and computers, Papert allows his students to design their own animals and toys by punching out directions on a typewriter-like computer keyboard. They then "draw" the figures in green lights on a television screen. The children get large and lively doses of mathematical training as they figure out the proper angles and curves to form their animals. Called "turtle geometry," this new math gives a free rein to the students' imaginations. "We have never found a kid who did not learn to program the computer," says Papert. "But we have found children who have gone off and programed it in unusual ways."

Joji Iisaka: Extending Man's Senses

Eleven years ago, Joji Iisaka was engaged in a bit of exotic research to complete his doctorate in nuclear physics when he learned that someone else—using a computer—had produced in a matter of hours the same results he had been working toward for two years. It was a bitter experience for Iisaka and it led him to switch disciplines from nuclear physics to computer science. "If you can't beat them," he says now, "you might as well join them." But Iisaka has [illegible] much more than simply join the [illegible]. In fact, he has led computer sci[illegible] into the new and vital area of using machines as super-sensitive eyes to scan and analyze visual images.

Now 39 and an advisory researcher at IBM Japan's Scientific Center, Iisaka [illegible] work as leading the industry [illegible] new paths. "A lot of computer scientists have been interested in [illegible] processing of numbers and [illegible]ers," he says. "But images are [illegible] important in man's understanding and recognition of objects and in bringing people into consensus on social [illegible]s."

[illegible] Iisaka's image-processing systems have been used to detect cancerous cells and abnormal chromosomes in mass-medical screenings and to analyze aerial photos for land use, the location of resources, urban development and road construction. Environmentalists have used Iisaka's method to study pollution patterns and astronomers have found that computers can help them plot the movement of stars and planets. Future areas of application now seem virtually boundless and Iisaka clearly has no regrets about leaving physics for computers. "I was getting disgusted with the theory-for-theory's-sake approach in the Ivory Tower," he says.

Michael L. Dertouzos: Planner for the Future

A native of Athens, Michael Dertouzos, 38, is another computer whiz kid drawn to America's acropolis of computer research at MIT. As head of the university's Project MAC (derived from two acronyms: Machine-Aided Cognition and Multiple-Access Computer), Dertouzos directs a broad research program aimed at anticipating the problems which widespread computer use will bring in the future. Much of that research is geared to solving technical difficulties—how computer programs can be automatically generated, how to store and use information contained in memory banks more efficiently, how to use natural languages like English instead of a computer's bits and bites for communication between people and machines. But Dertouzos and his team are also deeply concerned with the social effects of the computer. At present, he has begun work on finding a way to guard against the unauthorized tapping of data from a computer.

A cigar-chomping bear of a man with a background in electrical engineering, Dertouzos's special field of interest is control robotics—the use of computers to control physical processes like manufacturing. He has also been a leader in introducing computer courses into MIT's engineering curriculum.

Dmitri G. Zhimerin: Computerizing Russia

A shadowy figure, he toiled quietly for over 40 years in the Soviet scientific bureaucracy as an electric-power specialist. Adept at political maneuvering, he survived the purges that cut short other careers and suffered only one demotion in his climb to the top. And now, Dmitri Zhimerin, 68, holds one of the key jobs in all of Soviet science, first deputy chairman of the Council of Ministers' State Committee on Science and Technology.

Although he might not admit it, Zhimerin owes his continued ascendency to the computer. Soon after becoming first deputy minister, he became one of the first public advocates of using the computer to overhaul the Soviet Union's cumbersome economic bureaucracy. Writing in Pravda, Zhimerin stressed the need to incorporate computer technology in economic planning and called for a "nationwide automated system for gathering and processing information, the first automated management system of its type and magnitude in the world." Since proclaiming those grandiose intentions, Zhimerin has guided Russia's computer research toward his goal and has also decided on which kinds of computer technology to import from abroad. He has skillfully consolidated his power and now seems to be the man who may finally computerize the Soviet economy all the way into the space age.

Problem Solvers

Kenset Yoshida

(Clockwise from left) Papert, Iisaka, Zhimerin, Dertouzos: Using machines to plan the future and to help man learn about himself

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
A.I. LABORATORY

Artificial Intelligence
Memo No. 247

October 1971

LOGO
Memo No. 2

TEACHING CHILDREN THINKING[1,2]

Seymour Papert*

This work was supported by the National Science Foundation under grant number GJ-1049 and conducted at the Artificial Intelligence Laboratory, a Massachusetts Institute of Technology research program supported in part by the Advanced Research Projects Agency of the Department of Defense and monitored by the Office of Naval Research under Contract Number N00014-70-A-0362-0002.

*This paper is deeply influenced by Cynthia Solomon and Marvin Minsky.

[1]Presented at the Proceedings of IFIPS World Congress on Computers and Education, Amsterdam, The Netherlands, 1970.

[2]To be published in Mathematics Teaching (The Association of Teachers of Mathematics, Leicester, England: 1972).

This paper is dedicated to the hope that someone with power to act will one day see that contemporary research on education is like the following experiment by a nineteenth century engineer who worked to demonstrate that engines were better than horses. This he did by hitching a 1/8 HP motor in parallel with his team of four strong stallions. After a year of statistical research he announced a significant difference. However, it was generally thought that there was a Hawthorne effect on the horses.

1. Introduction

The phrase "technology and education" usually means inventing new gadgets to teach the same old stuff in a thinly disguised version of the same old way. Moreover, if the gadgets are computers, the same old teaching becomes incredibly more expensive and biased towards its dullest parts, namely the kind of rote learning in which measurable results can be obtained by treating the children like pigeons in a Skinner box.

The purpose of this essay is to present a grander vision of an educational system in which technology is used not in the form of machines for processing children but as something the child himself will learn to manipulate, to extend, to apply to projects, thereby gaining a greater and more articulate mastery of the world, a sense of the power of applied knowledge and a self-confidently realistic image of himself as an intellectual agent. Stated more simply, I believe with Dewey, Montessori and Piaget that children learn by doing and by thinking about what they do. And so the fundamental ingredients of educational innovation must be better things to do and better ways to think about oneself doing these things.

I claim that computation is by far the richest known source of these ingredients. We can give children unprecedented power to invent and carry out exciting projects by providing them with access to computers, with a suitably clear and intelligible programming language and with peripheral devices capable of producing on-line real-time action.

> Examples are: spectacular displays on a color scope, battles between computer controlled turtles, conversational programs, game-playing heuristic programs, etc. Programmers can extend the list indefinitely. Others can get the flavor of the excitement of these ideas from movies I shall show at the IFIPS meeting.

Thus in its embodiment as the physical computer, computation opens a vast universe of things to do. But the real magic comes when this is combined with the <u>conceptual power</u> of theoretical ideas associated with computation.

Computation has had a profound impact by concretizing and elucidating many previously subtle concepts in psychology, linguistics, biology, and the foundations of logic and mathematics. I shall try to show how this elucidation can be projected back to the initial teaching of these concepts. By doing so much of what has been most perplexing to children is turned to transparent simplicity; much of what seemed most abstract and distant from the real world turns into concrete instruments familiarly employed to achieve personal goals.

curious assumption that our choice is this: <u>either</u> teach the children half-baked cognitive theory <u>or</u> leave them in their original state of cognitive innocence. Nonsense. The child does not wait with a virginally empty mind until we are ready to stuff it with a statistically validated curriculum. He is constantly engaged in inventing theories about everything, including himself, schools and teachers. So the real choice is: <u>either</u> give the child the best ideas we can muster about cognitive processes <u>or</u> leave him at the mercy of the theories he invents or picks up in the gutter. The question is: who can do better, the child or us? Let's begin by looking more closely at how well the child does.

2. The Don't-Think-About-Thinking Paradox

It is usually considered good practice to give people instruction in their occupational activities. Now, the occupational activities of children are learning, thinking, playing and the like. Yet, we tell them nothing about those things. Instead, we tell them about numbers, grammar and the French revolution; somehow hoping that from this disorder the really important things will emerge all by themselves. And they sometimes do. But the alienation-dropout-drug complex is certainly not less frequent.

In this respect it is not a relevant innovation to teach children also about sets and linguistic productions and Eskimos. The paradox remains: why don't we teach them to think,to learn, to play? The excuses people give are as paradoxical as the fact itself. Basically there are two. Some people say: we know very little about cognitive psychology; we surely do not want to teach such half-baked theories in our schools! And some people say: making the children self-conscious about learning will surely impede their learning. Asked for evidence they usually tell stories like the one about a millipede who was asked which foot he moved first when he walked. Apparently the attempt to verbalize the previously unconscious action prevented the poor beast from ever walking again.

The paradox is not in the flimsiness of the evidence for these excuses. There is nothing remarkable in that: all established doctrine about education has similarly folksy foundations. The deep paradox resides in the

> Mathematics is the most extreme example. Most children never see the point of the formal use of language. They certainly never have the experience of making their own formalism adapted to a particular task. Yet anyone who works with a computer does this all the time. We find that terminology and concepts properly designed to articulate this process are avidly seized by the children who really want to make the computer do things. And soon the children have become highly sophisticated and articulate in the art of setting up models and developing formal systems.

The most important (and surely controversial) component of this impact is on the child's ability to articulate the working of his own mind and particularly the interaction between himself and reality in the course of learning and thinking. This is the central theme of this paper, and I shall step back at this point to place it in the perspective of some general ideas about education. We shall return later to the use of computers.

3. The Pop-Ed Culture

One reads in Piaget's books about children re-inventing a kind of Democritean atomic theory to reconcile the dissappearance of the dissolving sugar with their belief in the conservation of matter. They believe that vision is made possible by streams of particles sent out like machine gun bullets from the eyes and even, at a younger age, that the trees make the wind by flapping their branches. It is criminal to react (as some do) to Piaget's findings by proposing to teach the children "the truth." For they surely gain more in their intellectual growth by the act of inventing a theory than they can possibly lose by believing, for a while, whatever theory they invent. Since they are not in the business of making the weather, there is no reason for concern about their meteorological unorthodoxy. But they are in the business of making minds--notably their own--and we should consequently pay attention to their opinions about how minds work and grow.

There exists amongst children, and in the culture at large, a set of popular ideas about education and the mind. These seem to be sufficiently widespread, uniform and dangerous to deserve a name, and I propose "The Pop-Ed Culture." The following examples of Pop-Ed are taken from real children. My samples are too small for me to guess at their prevalence. But I am sure very similar trends must exist very widely and that identifying and finding methods to neutralize the effects of Pop-Ed culture will become one of the central themes of research on education.

Examples of Pop-Ed Thinking

(a) Blank-Mind Theories. Asked how one sets about thinking a child said: "make your mind a blank and wait for an idea to come." This is related to the common prescription for memorizing: "keep your mind a blank and say it over and over". There is a high correlation, in my small sample, between expressing something of this sort and complaining of inability to remember poetry!

(b) Getting-It Theories. Many children who have trouble understanding mathematics also have a hopelessly deficient model of what mathematical understanding is like. Particularly bad are models which expect understanding to come in a flash, all at once, ready made. This binary model is expressed by the fact that the child will admit the existence of only two states of knowledge often expressed by "I get it" and "I don't get it." They lack--and even resist--a model of understanding something through a process of additions, refinements, debugging and so on. These children's way of thinking about learning is clearly disastrously antithetical to learning any concept that cannot be acquired in one bite.

(c) Faculty Theories. Most children seem to have, and extensively use, an elaborate classification of mental abilities: "he's a brain", "he's a retard", "he's dumb", "I'm not mathematical-minded". The disastrous consequence is the habit of reacting to failure by classifying the problem as too hard, or oneself as not having the required aptitude, rather than by diagnosing the specific deficiency of knowledge or skill.

4. Computer Science as a Grade School Subject

Talking to children about all these bad theories is almost certainly inadequate as an effective antidote. In common with all the greatest thinkers in the philosophy of education I believe that the child's intellectual growth must be rooted in his experience. So I propose creating an environment in which the child will become highly involved in experiences of a kind to provide rich soil for the growth of intuitions and concepts for dealing with thinking, learning, playing, and so on. An example of such an experience is writing simple heuristic programs that play games of strategy or try to outguess a child playing tag with a computer controlled "turtle".

Another, related example, which appeals enormously to some children with whom we have worked is writing teaching programs. These are like traditional CAI programs but conceived, written, developed and even tested (on other children) by the children themselves.

> (Incidentally, this is surely the proper use for the concept of drill-and-practice programs. Writing such programs is an ideal project for the second term of an elementary school course of the sort I shall describe in a moment. It is said that the best way to learn something is to teach it. Perhaps writing a teaching program is better still in its insistence on forcing one to consider all possible misunderstandings and mistakes. I have seen children for whom <u>doing</u>

> arithmetic would have been utterly boring and alienated become passionately involved in writing programs to teach arithmetic and in the pros and cons of criticisms of one another's programs like: "Don't just tell him the right answer if he's wrong, give him useful advice." And discussing what kind of advice is "useful" leads deep into understanding both the concept being taught and the processes of teaching and learning.)

Can children do all this? In a moment I shall show some elements of a programming language called LOGO, which we have used to teach children of most ages and levels of academic performance how to use the computer. The language is always used "on-line", that is to say the user sits at a console, gives instructions to the machine and immediately gets a reaction. People who know languages can think of it as "baby LISP", though this is misleading in that LOGO is a full-fledged universal language. Its babyish feature is the existence of self-contained sub-sets that can be used to achieve some results after ten minutes of instruction. Our most extensive teaching experiment was with a class of seventh grade children (twelve year olds) chosen near the average in previous academic record. Within three months these children could write programs to play games like the simple form of NIM in which players take 1, 2, or 3 matches from a pile; soon after that they worked on programs to generate random sentences--like what is sometimes called concrete poetry--and went on from there to make conversational and teaching programs. So the empirical evidence is very strong that we can do it, and next year we shall be conducting a more extensive experiment with fifth grade children. The next sections will show some of the elementary exercises we shall use in the first weeks of the course. They will also indicate another important aspect of having children do their work with a computer: the possibility of working on projects with enough duration for the child to become personally--intellectually and emotionally--involved. The final section will indicate a facet of how more advanced projects are handled and how we see the effects of the kind of sophistication developed by the children.

5. You Can Take the Child to Euclid, But You Can't Make Him Think

Let's go back to Dewey for a moment. Intellectual growth, he often told us, must be rooted in the child's experience. But surely one of the fundamental problems of the school is how to extend or use the child's experience. It must be understood that "experience" does not mean mere busy work: two children who are made to measure the areas of two triangles do not necessarily undergo the same experience. One might have been highly involved (e.g. anticipating the outcome, being surprised, guessing at a general law) while the other was quite alienated (the opposite). What can be done to involve the mathematically alienated child? It is absurd to think this can be done by using the geometry to survey the school grounds instead of doing it on paper. Most children will enjoy running about in the bright sun. But most alienated children will remain alienated. One reason I want to emphasize here is that surveying the school gro-nds is not a good research project on which one can work for a long enough time to accumulate results and become involved in their development. There is a simple trick, which the child sees or does not see. If he sees it he succeeds in measuring the grounds and goes back to class the next day to work on something quite different.

Contrast this situation with a different context in which a child might learn geometry. The child uses a time-shared computer equipped with a CRT. He programs on-line in a version of the programming language LOGO, which will be described in more detail below.

On the tube is a cursor point with an arrow indicating a direction. The instruction

```
FORWARD 100
```

causes the point to move in the direction of the arrow through 100 units of distance. The instruction

```
ROTATELEFT 90
```

causes the arrow to rotate 90°.

The child knows enough from previous experience to write the following almost self-explanatory program:

```
TO CIRCLE
FORWARD 1
ROTATELEFT 1
CIRCLE
END
```

The word "TO" indicates that a new procedure is to be defined, and it will be called "CIRCLE". Typing

```
CIRCLE
```

will now cause the steps in the procedure to be executed one at a time. Thus:

1st Step:	FORWARD 1	The point creeps ahead 1 unit.
2nd Step:	ROTATELEFT 1	The arrow rotates 1°.
3rd Step:	CIRCLE	This is a recursive call; naturally it has the same effect as the command CIRCLE typed by the child. That is to say, it initiates the same process:

1st Step:	FORWARD 1	The point creeps on, but in the new, slightly different direction.
2nd Step:	ROTATELEFT 1	The arrow now makes an angle of 2° with its initial direction.
3rd Step:	CIRCLE	This initiates the same process all over again. And so on, forever.

It is left as a problem for the reader to discover why this point will describe a circle rather than, say, a spiral. He will find that it involves some real geometry of a sort he may not yet have encountered (See answer at end of paper.). The more immediately relevant point is that the child's work has resulted in a certain happening, namely a circle has appeared. It occurs to the child to make the circle roll? How can this be done? A plan is easy to make:

> Let the point go round the circle once.
>
> Then FORWARD 1
>
> Then repeat.

But there is a serious problem! The program as written causes the point to go round and round forever. To make it go just once round we need to give the procedure an <u>input</u> (in more usual jargon: a variable).

This input will be used by the procedure to remember how far round it has gone. Let's call it "DEGREES" and let it represent the number of degrees still to go, so it starts off being 360 and ends up 0. The way this is written in LOGO is:

```
TO CIRCLE :DEGREES              :DEGREES means: the thing whose name
                                is "DEGREES".
IF  :DEGREES = 0   STOP
FORWARD 1
ROTATELEFT 1
CIRCLE  :DEGREES - 1            Each time round the number of degrees
                                remaining is reduced by 1.
END
```

Now we can use this as a sub-procedure for ROLL:

```
TO ROLL
CIRCLE 360
FORWARD 10
ROLL
END
```

Or, to make it roll a fixed distance:

```
TO ROLL  :DISTANCE
IF  :DISTANCE = 0   STOP
CIRCLE 360
FORWARD 10
ROLL  :DISTANCE - 1
END
```

Or we can make the circle roll around a circle:

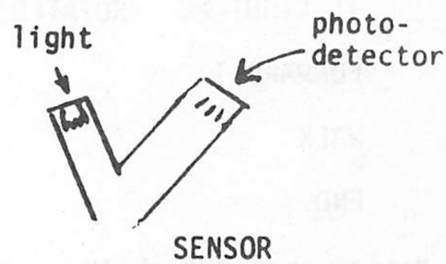
```
TO FUNNYROLL
CIRCLE 360
FORWARD 10
ROTATELEFT 10
FUNNYROLL
```

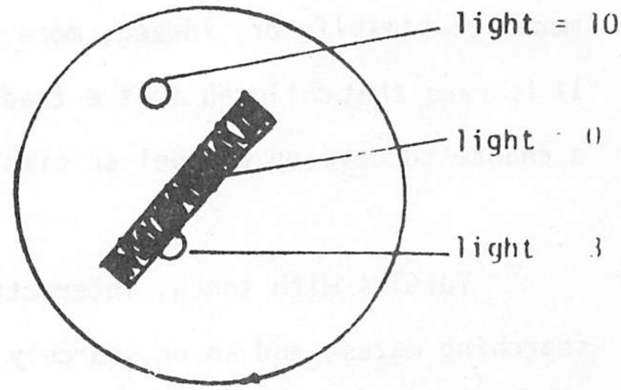
These examples will, if worked on with a good dose of imagination, indicate the sense in which there are endless possibilities of creating even more, but gradually more, complex and occasionally spectacularly beautiful effects. Even an adult can get caught up in it! Not every child will. But if he does, the result is very likely to be a true extension of his experience in Dewey's sense. And evidence is accumulating for the thesis that there is scarcely any child who cannot be involved in some computational project.

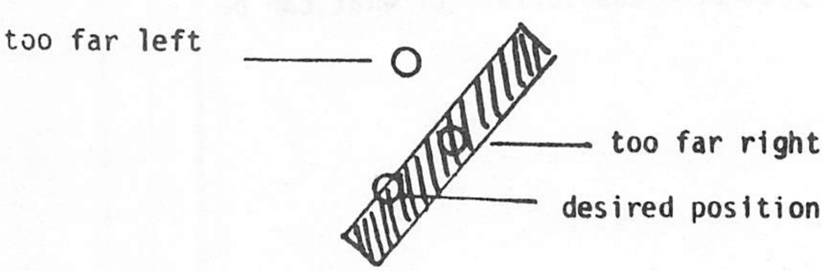
The next two sections will discuss two other peripheral devices suitable for a computation laboratory in an elementary school: a programmable vehicle and a music generator. There is, of course, no end to what one could invent. At M.I.T. we are thinking in terms of soon adding mechanical manipulators, psychedelic light shows in a reactive environment, apparatus for automated experiments in animal psychology, etc., etc., etc.

6. The Love of the Turtle

At M.I.T. we use the name "Turtle" for small computer controlled vehicles, equipped with various kinds of sense, voice and writing organs. Turtles can be controlled by the same commands used in the previous section to describe Graphics. They can be made to draw or to move about without leaving a visible trace. Procedures to achieve this are exactly like the procedures for CRT Graphics. However sense organs allow another interesting dimension of work. An interesting simple one is a reflectivity sensor held close to the floor. A LOGO operation called "LIGHT" has an integer value between 0 and 10, depending on the relfectivity of the surface. Suppose we wish to program the turtle to follow the left edge of a black line on a white floor. Using an important heuristic we encourage the child to study himself in the situation, and try to simulate his own behavior. The key idea, of course is to use feed-back according to the following plan:







COLOR	LIGHT	POSITION ERROR	CORRECTION
Mainly Black	small value	Too far right	ROTATELEFT
Equal Black & White	5	O.K.	Nothing
Mainly White	big value	left	ROTATERIGHT.

This leads to the procedure:

```
TO WALK
IF LIGHT <4   ROTATELEFT
IF LIGHT >6   ROTATERIGHT
FORWARD 1
WALK
END.
```

Notice that the child can think of the program as a very simple formal model of himself, or, indeed, more justly, of a moth flying to a light. It is rare that children in the traditional context of math-science get a chance to develop a model so simple.

Turtles with touch, interactive behavior with several turtles, searching mazes, and so on scarcely scratch the surface of what can be done with these beasts.

7. Music

Just as the computer can be instructed to move a point on a TV display or make a turtle move or print a word, it can be instructed to sing a note. The LOGO instruction SING follwoed by an input to indicate a note (represented by 1 ... 7) or a time. A program can be written thus:

```
TO MARY
SING 3
SING 2
SING 1
SING 2
SING 3
SING 3
END
```

The command

MARY

will cause the computer to sing the tune.

The program

```
TO CHANTMARY
MARY
CHANTMARY
END
```

will cause the tune to be repeated indefinitely. Programs can be written to speedup, slowdown, raise, lower, transpose, sing in chorus, etc., etc. Children can use the computer as a super musical instrument. They can compose at the typewriter and hear their creations played perfectly. They can make and undo small changes. They can cause the turtle or the CRT display to move to music and so on endlessly.

8. Case Histories form the Muzzey Jr. High School Experiment

The following piece is extracted verbatim from a remport on the seventh grade teaching experiment performed at Muzzey Jr. High School at Lexington.

8.1. Problem vs. Project

The most exciting single aspect of the experiment was that most of the children acquired the ability and motivation to work on projects that extend in time over several days, or even weeks. This is in marked contrast with the usual style of work in mathematics classes, where techniques are taught and then applied to saml1 repetitive exercise problems. It is closer, in ways that are essential to the later argument here, to the work style of some art classes where children work for several weeks on making an object; a soapcarving for example. The similarity has several dimensions. The first is that the duration of the process is long enough for the child to become involved, to try several ideas, to have the experience of putting something of oneself in the final result, to compare one's work with that of other children, to discuss, to criticise and to be criticised on some other basis that "right or wrong." The point about criticism is related to a sense of creativity that is important in many ways which we shall talk about later--including, particularly, its role in helping the child develop a healthy self-image as an active intellectual agent.

Let's take an example. A continuing project over the last third of the year was working on various kinds of "language generating" programs. The children studied a program (given as a model) which generated two word sentences like:

CATS RUN
DOGS SHOUT
CHILDREN BITE
DOGS RUN
CATS RUN
.
.
.

The assignment was to study the model and go on to make more interesting programs. The sample printout that follows brought great joy to its creator who had worked hard on mastering the mathematical concepts needed for the program, on choosing sets of words to create an interesting effect and on converting her exceedingly bague (and unloved) knowledge about grammar into a useful, practical form.

```
INSANE RETARD MAKES BECAUSE SWEET SNOOPY SCREAMS
SEXY WOLF LOVES THATS WHY THE SEXY LADY HATES
UGLY MAN LOVES BECAUSE UGLY DOG HATES
MAD WOLF HATES BECAUSE INSANE WOLF SKIPS
SEXY RETARD SCREAMS THATS WHY THE SEXY RETARD HATES
THIN SNOOPY RUNS BECAUSE FAT WOLF HOPS
SWEET FOGINY SKIPS A FAT LADY RUNS
```

The next class assignment was to generate mathematical sentences which were later used in "teaching programs." For example:

```
8 * BOX + 6 = 48
WHAT IS BOX?
```

Finally, in the last weeks, someone in the class said she wanted to make a French sentence generator...for which she spurned advice and went to work. In the course of time other children liked the idea and followed suit -- evoking from the first girl prideful complaints like "why do they all have to take my idea?" The interesting feature was that although they took her idea, they imprinted it strongly with their own personalities, as shown by the following case studies:

> <u>K.M.</u> The girl who initiated the project. Thoughtful, serious about matters that are important to her, often disruptive in class. Her approach to the French project was to begin by writing procedures to conjugate all the regular verbs and some irregular ones. The end of the school year fell before she had made a whole sentence generator. But she did have a truly professional program, completely debugged and working with great competence at conjugating -- e.g. given VOUS and FINIR as inputs it would reply: VOUS FINISSEZ.

MR A gay, exuberant girl who made the "SEXY COMPUTER" program quoted above. Only half seriously she declared her intention of making the first operational French sentence generator. In a sense she did--but with cavalier disregard for the Academy's rules of spelling and grammar!

JC A clear mind with a balanced sense of proportion. Deliberately decided to avoid the trap of getting so involved with conjugation that no sentence would ever be generated. Too serious to allow his program to make mistakes. Found a compromise: he would make a program that knew only the third person--but was still non-trivial because it did know the difference between singular and plural as well as the genders: thus it would say

LE BON CHIEN MANGE

but

LES BONNES FILLES MANGENT.

8.2. A Detail from a Child's Mathematical Research Project

The fine texture of the work on projects of this sort can only be shown by case studies. The following vignette needs very little reference to LOGO--thus illustrating how the projects are more than programming.

J is the author of the last French program mentioned. A little earlier he is working on generating equations as part of a project to make "a program to teach 8th grade algebra." He has perfected a program to generate equations with co-efficients in the range of 0-9 using a "random" number generator. His present problem is to obtain larger coefficients.

First Solution: Almost everyone tries this: get bigger numbers by adding smaller ones obtained from the old procedure. Amongst other considerations, this looks like a good technique that has often paid well: use old functions to define new ones.

Consequences: J chooses his equation generator but soon finds some annoying features:

> The new coefficients are in the range 0-18, which is unnatural and not very big.
>
> There is a preference for some numbers e.g. 9 comes up ten times as often as 18!

Comment: The first problem can be alleviated by adding more numbers. One can even add a random number of random numbers. But this aggravates the second problem. J understands this qualitatively but does not see a way out. It is interesting that children and adults often have a resistance to making numbers by "non-numerical" operations. In this case the solution is to concatenate the single digit random numbers instead of adding them. LOGO has a simple way to express this and J is quite accustomed to making non-numerical strings by concatenation. In fact this is how he makes the equation! Nevertheless he resists

The problem is discussed in a class meeting and after some prompting everyone suddenly "discovers" the solution.

New Solution: J changes his program, now making numbers up to 99 by concatenation; he does some crude check of uniformity of distribution and tries his program.

Disaster: For a while it seems to go well. But in the course of playing with the "teaching program" a user types 5 and is surprised to get a reply like:

> You knucklehead; You took 11 seconds and your answer is wrong. The answer is 05. Here is some advice...etc.

Comment: Poor J will get the sympathy of every mathematician who must at some stage have tried to generalize a result by extending the domain of an innocent looking function only to find that the extended function violates some obscure but essential condition. He is also in the heart of the problem of representation. Is "05" a good representation? Yes, no... have your choice but face the consequences and be consistent. J's problem is that his procedures accept "05" for arithmetic operations but not for the test of identity!

Solution: Change the identity test or peel off the leading zero. J chose the latter. His program worked for a while and was used, in ways that we shall see, to great effect.

New Step: Later J was urged to allow negative numbers. He found a good way: use the one digit random number generator to make a binary decision:

If less than 5, positive

Otherwise, negative.

<u>That Problem Again</u>: J had a program working perfectly with negatives. Then one day decided to make it more symmetrical by using +5 and -5 for positive and negative. This brought him back to the old problems raised by differences between the machine's represetntation and the human user's. At this point the year ended with J's program not quite as effective as it had been at its peak.