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8. *Expanding Children's Concepts of Number, Space and Operation*

Symbols

OZNAKI, the Polish word meaning 'symbols', is the code name for a project in which children learn to use the symbols of mathematics. In OZNAKI a symbol on a key denotes both a mathematical operation and a command directed at a mathematical robot, called a NAKI. The activities of a NAKI model mathematical operations so that as children learn to control the NAKI, they are learning to *use* mathematics. Mathematical relations are modelled by real, observable effects as children program the NAKI to move, sing, dance or lay a trail. As children advance through OZNAKI, they gain increasing opportunity to play, experiment, elaborate and develop their own mathematical creations.

Mathematics is often described as involving 'abstract' ideas. This is quite true, but not in the sense that the words seem to suggest. Mathematical ideas have to be abstracted from experience. Without the concrete experience, there can be no mathematical idea. Of course the more sophisticated the mathematician, the more polished will be his or her presentation of completed work. But in actually solving problems, the better the mathematician, the more concrete his or her thinkipg. In my own studies of problem-solving by expert mathematicians and physicists, these experts were encouraged to think aloud Cloud think') while attempting particular problems. I observed the experts squeezing, stroking and otherwise manipulating with their hands; spatially linked ideas seemed to direct their attack.

The idea of using 'concrete material' to teach mathematics is not new. Dr Maria Montessori developed several simple items as aids in acquiring number concepts. Many primary schools use Cusinere rods sets of coloured rods with, for instance, the green rod 6 centimetres long, and the white unit rod precisely 1 centimetre long. However, it is impossible using wooden or plastic material to model the idea of definition. In fact it is very difficult using blocks of toy soldiers to model convincingly the basic idea of addition. If there are two objects before a child, the teacher might add one more. But to the child, this addition will be only a rearrangement, the teacher merely moving one object nearer to hand. Thus in the case of addition, conventional concrete materials can only model the 'before' and 'after', not the mathematical operation itself.

The Wizard's Box

In order to model mathematical symbols, one needs a link between the world of symbols and the physical world. One needs a machine that can both manipulate symbols and control or at least alter the physical world. Computers are symbol manipulation machines, but generally they only control printers and card readers.

In OZNAKI we have incorporated the symbol manipulation power of a computer into an electron's controller, to make what we call a 'Wizard Box'. The Wizard who runs the Box is of course the Wizard of Oznaki.

A teacher need know nothing of computers or computing to use a Wizard Box in class. However, to understand the reasons why such a symbolic controller can be made cheaply one needs to know the basis of the computer revolution coming in the 1980s. The Wizard Boxes currently used are 'personal computers' sold to computer hobbyists at prices between $600 and $2000. These microcomputers are based on electronic devices called microprocessors, costing in 1978 about $10. With the predictable growth in computer technology over the next eight years, one can confidently plan for complete `Wizard Boxes' of only book size, and costing about $250.

OZNAKI is not Computer Aided Instruction (CAI). CAI uses computer technology to verify the child's response to a graduated set of questions (`programmed learning'). In OZNAKI computer power provides a mathematical learning environment, called MathsLab, in which children explore mathematics by producing real, observable effects. Various teaching modules are being developed, using OZNAKI, in which children can play, experiment, elaborate and develop their own mathematical creations.

The PLUSMINUS

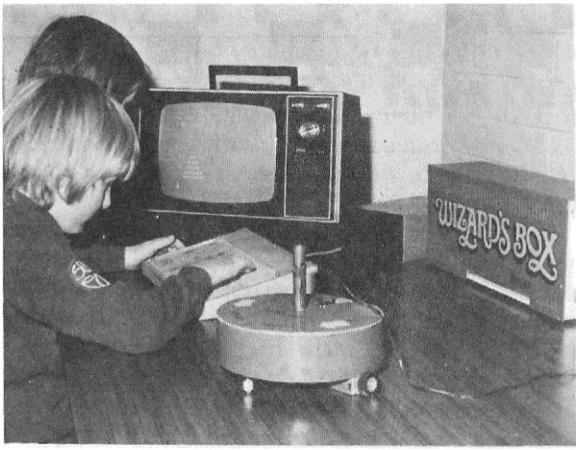


Figure 8.1 *The Wizard Box being used by two seven-year-old pupils of Nillumbik Co-operative School. On the screen is the top of a 'Christmas Tree' they are creating. The special keyboard they are using features overlays(which label keys in use and hide others). In the foreground is the robot ZONKY II.*

The child who plays with the PLUSMINUS is confronted by two large keys, marked ‘+' and ‘-‘ and a TV screen, on which a large '0' is displayed. If the large ‘+' key is struck, there is a sharp metallic click, a train appears on the screen, and the number displayed becomes a '1'. Each further time the ‘+' key is struck, one further train appears, and the new total of trains is displayed. If the key is struck, there is a loud click, the train on the end of the row disappears, and the number display is altered to show the new total. In place of trains, birds or dogs may be displayed.

In PLUSMINUS the number display, together with the row of screen animals, provides the same sort of embodiment of numbers as is given by the more traditional concrete materials. The PLUSMINUS associates a digit with a definite number of objects, and with the number of times the '+' key has been struck in counting up to the screen total (or counting down to make the TV animals disappear). But unlike rods, the PLUSMINUS also provides a concrete representation for the symbols + ' and '—'; the actual *operations* of addition/subtraction are modelled. Traditional materials can only show the before and after pictures for an arithmetical operation, and cannot model the operation itself.

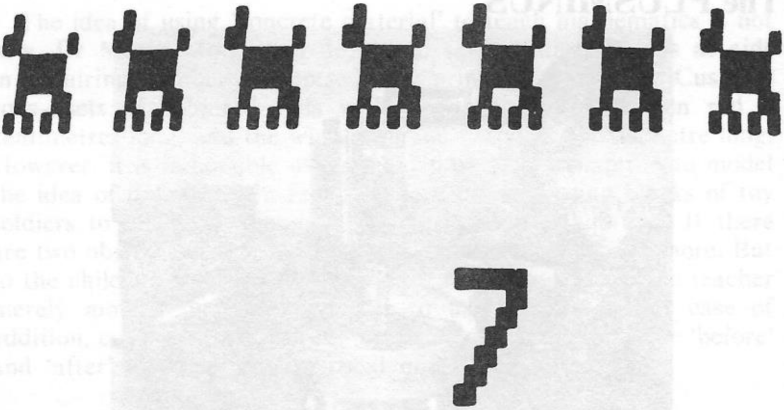
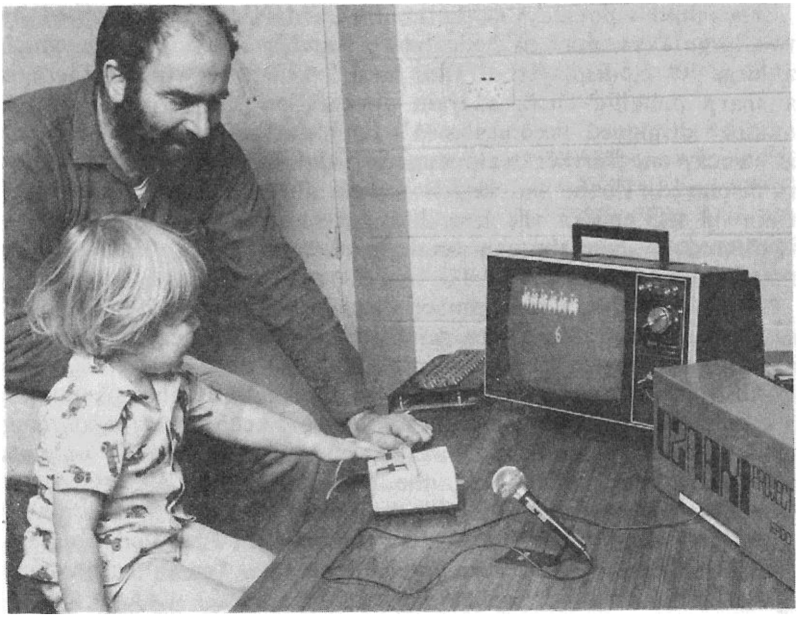


Figure 8.2 *The* PLUSMINUS *program and user. On the TV are displayed six trains, together with the digit 6. The two-year-old child is striking the '—' key of a large keyboard, which will cause one train to vanish. Also visible is the microphone used for speech input.*



Speech Input

The original PLUSMINUS constructed for the OZNAKI project featured a row of nine bright lights, an electronic number display, and two very large keys marked ' and `—'. In Cohen, 1976 (OZNAKI), there is a picture of this calculator-type PLUSMINUS operated by a 2-year-old. The development of the OZNAKI microcomputer, our Wizard's Box, led to PLUSMINUS becoming a program controlled by the microcomputer.

Because of the incredible flexibility of computer control, PLUSMINUS has far greater capabilities than those described so far, and further capabilities could be added at the teacher's discretion. Thus by providing children with a larger keyboard, one can enable them to select the type of screen animal; striking a key displaying a digit will make the appropriate number of TV animals (or trains) appear. The possibilities, if a larger keyboard included a multiplication key, are obvious.

Using surprisingly simple hardware, in conjunction with the software we have developed, it is possible for the PLUSMINUS, and other OZNAKI systems, to accept speech input. After a training session in which a child talks into a microphone attached to the microcomputer, these words, up to 32 in current programs, of that speaker can be recognised. In the Speech PLUSMINUS the words `plus one' function exactly like the `-1- ' keystroke, and the words `minus one' like the `—' key. The words 'six dogs' will cause just six dogs to appear on the TV screen.

Significance of the PLUSMINUS

The PLUS MINUS provides concrete modelling for the operations of addition and subtraction. A more detailed understanding of the significance of the PLUSMINUS can be derived from Gelman's studies (1972, 1975) of the development of early number concepts. To quote Gelman: 'The cognitive processes by which people determine some quantity, such as the numerosity of a set of objects, are called *estimators.* The cognitive processes by which people determine the consequences of transforming a quantity in various ways are called *operators.'* As Gelman asserts, operators are more central to a mature conception of number. It appears from the evidence, including the studies of Sinclair and Inhelder at Geneva, that the child's 'number scheme is a central quantity scheme which facilitates the development of other quantity concepts'. It is in fact rather difficult to test young children's number concepts, but Gelman developed a technique. In her experiments preschool children were trained to anticipate a certain arithmetical relationship between two collections of objects. Then, using 'magic', the interviewer surreptitiously altered one collection. The child's reaction of surprise gave a non-verbal indication of possession or otherwise of arithmetical operators.

ZONKY

ZONKY is a robot that crawls about the floor or table-top connected by just three thin wires to the microcomputer Wizard Box. On ZONKY are marked the 'forward' direction, and the directions for `right' and 'left' turns (on the spot) which take place about a central point where a felt-tipped pen is mounted. This pen, if inserted, marks out the robot's trail. The original ZONKY was a model tank moving on tracks. The latest automaton, ZONKY II, is of circular plan, with the pen-mounting hole in the geometric centre.

The basic movement commands for ZONKY are 'F' for forward, 'B' for backward, 'R' for right, and 1' for left. While performing these movements the automaton can also be ordered to honk, 'H', or to light its lights, 'A'. A string of commands—like an English command—must be terminated by an exclamation mark, T. (There is a version of the command language for preschool children where the T is not required, and only one command at a time can be performed.) To illustrate, following the command 3AF 2HK! the robot makes three steps forward with its lights flashing, then makes two turns right (clockwise) on the spot while honking its horn. In between each forward step or unit turn there is a one-second delay. The commands punched in by the student are visible on the TV screen; also displayed are the actual control words that are directed at ZONKY. Thus for the student's commands 3H F 2AR a further embodiment of number is supplied through the display on the screen of the ZONKY language words: aaaaaaaaaa aaaaaaaaaa aaaaaaaaaa ggggggggg ggggggggg. Note that corresponding to a unit motor command, there are precisely ten lower-case control characters displayed. This facilitates the introduction of decimals.

Algebra and Macros

Children directing ZONKY, and most other OZNAKI systems, actually name (`define') new symbols. There is one very special command on the keyboard, which is marked by the letter 'Z'. (This key is especially easy to locate on the left of the keyboard.) When this key is depressed, the following list of commands is to be *remembered,* all of them up to the exclamation mark T. And what is to be remembered can have a name chosen from 'V', 'W', 'X' or 'Y'.

A very simple example of the use of the remember command 'Z' is as follows. The command 'C' directs ZON KY to 'clang', when the robot's siren emits a somewhat bell-like sound. Suppose the child presses in sequence the keys 'Z', 'X', '3', 'C', T, then on the screen appears a message, X = 3C. This message is in conventional algebraic notation, which is a feature of OZNAKI. The message says that the command 'X' now is the same as three 'C' (`clang') commands. Thus if the student punches in 2X!, ZONKY will clang six times. Students can play 'guessing' games in which they ask one another such questions as 'What does X equal?', after demonstrating to the other child the effect of 4X.

Thus in playing with ZONKY children use a basic idea of algebra, the idea of definition, of making one symbol stand in place of others. Using OZNAKI, primary-school children use such algebraic ideas with facility. In OZNAKI the effects of definition are very obvious. At the start of a session with ZON KY, the commands 'V', 'W', 'X' and 'Y' cause absolutely nothing to happen. After using the 'Z' command, the symbol is defined in terms of other commands, and one can check this definition by seeing (and hearing) precisely how the command directs ZONKY. In traditional teaching the notion of 'definition' is presented in high school, under such formats as 'Let X stand for the unknown'. Such an X stands for an unknown number, whereas in OZNAKI all symbols are commands producing effects.

In computer science, when one symbol stands for a collection of other symbols, that symbol is called a *macro.* So the child actually uses the remember command to define 'V', 'W', 'X' and 'Y' macros. In macros the order of symbols is important. For instance, the command 2F 3L 2B3R could be remembered using the 'Z' command as the macro 'X'. Now a single 'X' command draws a V-like figure, and returns the NAKI to its original heading. On the command 6X! a 'zig-zag' is drawn. Looking again at the V figure and the 'zig-zag' one sees that the V macro drew a particular pattern element. In the 'zig-zag' that same pattern element was repeated, all the commands in one X macro being performed in order for each repetition. In a more complex figure, different parts might be associated with different macros. For instance, 'The X drew the head, the Y drew the body. . . . ' Notice how the child must use definition, and can readily do so.

The slash symbol '/' is the command that the character that follows is to be printed on the screen. Thus the command 6/A will cause AAAAAA to appear on the screen. Children often use the `/' command playfully. Thus following the series of commands:

```
ZV /T/A/N/I/A !

ZW / /I/S/ /A !

ZX / /C/A/T !

ZY V W X !
```

the command V! would cause the message TANIA IS A CAT to appear on the TV screen. On the command 3V! the message TANIA IS A CAT TANIA IS A CAT TANIA IS A CAT will appear. In one lesson involving primary-school children, one 10-year-old told another: 'X is Mark. Y is Judy. And V is me.' Obviously that child, on what was her third lesson, had not yet acquired a sophisticated understanding of such issues as the relation of an object to its name.

By using ‘/' not only can simple messages be made to appear on the TV screen, but also some simple patterns, such as a Christmas tree constructed from asterisks. There are some more advanced capabilities of the `/' command. Every time an alphabetical character is placed on the TV screen, the same character is also transmitted to the robot ZONKY. ZONKY only responds to certain lower-case characters, called 'control characters'. But suppose a child uses the ‘/' to put on the screen the ten characters aaaaaaaaaa, then ZONKY will take precisely one honking forward step. Thus the child can replace the built-in ZONKY commands, F etc. by macros that he or she has written.

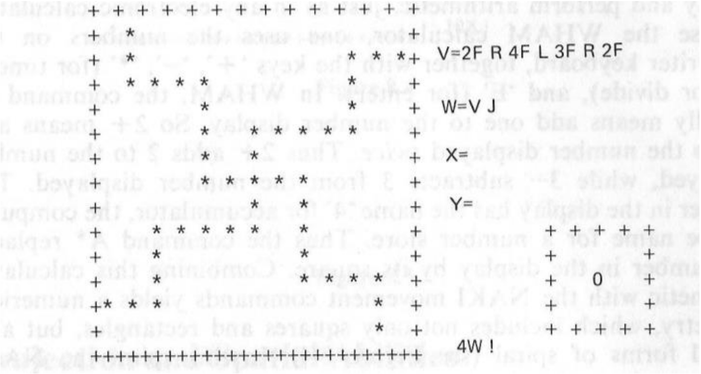
OZ-TIN MAN

The set of commands by which a child programs ZONKY constitutes a computing language. This is a special sort of computing language, as both built-in commands and the macros defined by the child are similarly used. Originally I called this computer language OZ, but later, in honour of the robot in the 'Wizard of Oz', the language was renamed `TINMAN'. In fact, for 'advanced' programming there are some differences between OZ and TINMAN. Chief amongst these is the use in TINMAN of the *accumulator*, or number store, of the same character as that described below under the heading WHAM.

WHAM

In WHAM the child controls the happenings on a TV screen with a typewriter-type keyboard. On the left side of the screen a square area in which a strange creature called a NAKI lives. This creature obeys the same basic commands as the OZNAK I robot ZONKY, namely 'forward', 'back', 'right' and 'left'. These commands are represented by the typewriter keys 'F','B', 'R' and 'L' However, the NAKI only ever turns through ninety degrees, for example from V (or South) on the TV screen, to < after the command R, when the NAKI's heading is to the West. As the NAKI roams his territory he leaves a trail of asterisks, so forming a design.

So far we have described the body of the WHAM NAKI, and the movements of this body. But the NAKI also has a visible *mind,* though strangely detached from the body. In the NAKI's mind is all that it has learned, together with the last command it obeyed. Of course to start with, in a session of WHAM, the NAKI knows nothing. But each time the 'Z' command is used to make it remember some list of commands by name, that list and its name are displayed in the mind. In the copy of the WHAM screen in Figure 8.2 the NAKI's body has wandered around the area fenced off with + signs. And to the right is the NAKI's mind.



```
V=2F R 4F L 3F R 2F
W=V J
X=
Y=
0
4W !
```

Figure 8.3

In WHAM, the command P clears the NAKI enclosure (bounded by = signs) and returns the NAKI to its home at the centre of the enclosure. So fifers is great freedom for the child to experiment while gaining experience with the basic movement commands. To draw the logo design shown in Figure 8.3, a child was asked to direct the NAKI from home to the top right-hand corner square by a 'squiggly' path, ending up heading east. (Overall, along this path, the NAKI has turned through 90 degrees.) The child was then asked to 'teach' the NAKI how to draw such a path by punching in Z, then V (the name of what is to be remembered) and then the commands that the NAKI followed in sequence. Thus the child had to work backwards along the marked path on the screen to fill out the memory list. This list is, of course, a symbolic representation of the path, symbols being what OZNAKI is about. Having checked that this V command was the one intended (clearing the screen and trying again if it was not), the child was ready for a direct suggestion from the teacher. The command J returns the NAKI to home, without changing the direction in which the NAKI is facing. So by punching in ZW V J ! the NAKI learns how to draw an entire arm of the logo, followed by a jump home. Having cleared the screen with the P command, the NAKI could then trace out the entire logo on the command 4W! Note how planning and problem decomposition are involved in drawing such a logo. Yet how delightful the patterns are; there is a stimulating visual reward for one's effort, a uniqueness and individuality.

But this is only part of the WHAM story. Also marked on the screen is a little area containing a number. This area is the number display of an electronic calculator. One can enter numbers in the display and perform arithmetic, just as in any electronic calculator. To use the WHAM calculator, one uses the numbers on the typewriter keyboard, together with the keys + '*' (for times), 7' (for divide), and `E' (for enter). In WHAM, the command + actually means add one to the number display. So 2 + means add one to the number displayed *twice.* Thus 2 + adds 2 to the number displayed, while 3— subtracts 3 from the number displayed. The number in the display has the name '4' for accumulator, the computer science name for a number store. Thus the command A* replaces the number in the display by its square. Combining this calculator arithmetic with the NAKI movement commands yields a numerical geometry, which includes not only squares and rectangles, but also several forms of spiral (see Figure 8.4). In this spiral the NAKI had started out from the centre of its territory when the number in the accumulator was zero: A = 0. On each X command, the NAKI moved forward A steps, turned right, then A was increased by 1. The creation of such a striking logo after a modest amount of mathematical labour is a reward of real impact for the child, hence the name WHAM.

The spiral in Figure 8.4 is closely related to the 'spiral' in the line-graphics of the computer language LOGO (Papert, 1971, 3). In

WHAM there is a 'Macro Repetition Theorem' very similar to the LOGO 'Round Trip Theorem'. The theorem is quite simple to state and, equally importantly, lends itself to discovery by the child. Suppose a particular macro, called X, is made up solely for the basic movement commands F, B, R, L and numbers. Then if the macro X alters the heading of the NAKI, the command 4X will send the NAKI on a trip that ends at the starting location. The theorem is false, however, if during its trip the NAKI strikes the boundary of its territory. Figure 8.5 gives a collection of examples of the Repetition Theorem

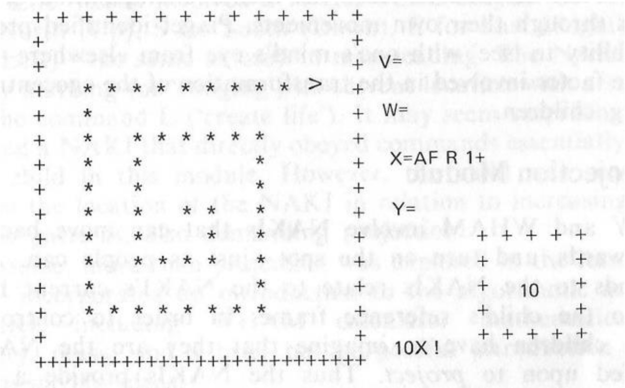


Figure 8.4

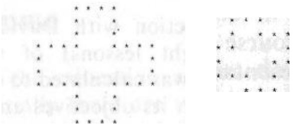


Figure 8.5

Projection and Spatial Abilities

An artist needs to develop a sense of space and perspective. And so does a mathematician. This need to develop spatial skills is not well understood, as is amply demonstrated by such trends as the elimination of geometry from high school syllabuses. In reading the biographies of famous mathematicians and scientists, from da Vinci to Einstein, it is easy to see how important mathematical concepts they developed often had a spatial basis. Many historians of science have commented on the link between the discovery of the rules of perspective in Art, and the foundation of modern mathematics. What is not as well appreciated is the 'epistemological' relation between the development of a person's spatial abilities and other mathematical abilities.

Piaget has described the child's concept of space essentially as follows. For younger children, space relates to themselves as focus (is egocentric). In seeking to understand how children's views of space develop, Piaget's comments are of special significance: . . . spatial concepts are internalised actions and not merely mental images of external things or events—or even the images of the results of actions'. That is, children learn the mental manipulation of spatial concepts through their own movements. Piaget identified projection the ability to 'see' with one's mind's eye from elsewhere—as the cognitive factor involved in the transformation of the egocentric view of young children.

The Projection Module

ZONKY and WHAM involve NAKIs that can move backwards and forwards, and turn on the spot just as people can. All the commands to the NAKIs relate to the NAKI's current heading — not to the child's reference frame. In order to control these NAKIs, children have to imagine that they are the NAKI, so are called upon to *project.* Thus the NAKIs provide a unique tool in developing spatial concepts in children at the stage of concrete operations.

The writer, in conjunction with David Green, devised a short introductory course (eight lessons) of OZNAKI in which the emphasis in presentation was calculated to develop skill in projection. It appears to be unique in its objectives and evaluation. The course, called the Projection Module, was given to children attending three primary schools and one high school near La Trobe University. In the first lesson children encountered ZONKY, our 'real' robot, then they progressed to WHAM, while the final lesson was on OZNAKI `Life'.

In dealing with ZONKY, and in later WHAM sessions, the children were encouraged to direct one of the group acting out the NAKI's planned moves. Thus they 'internalised' the spatial directives and took the opportunity to exercise projection. Before using the NAKIs to lay trails, preliminary tasks in both the ZONKY and the WHAM lessons involved walking the NAKI through mazes. This required the child to perform a very 'local' projection, in determining whether an obstacle was on the NAKI's right or left. Notice the progression from projecting on to a fellow pupil, on to the 'real' robot ZONKY, on to the WHAM NAKI.

In WHAM, children were encouraged to use direct commands to draw some simple figure, then to work from the screen figure to write down the definition of an X (or Y, V, W) that would draw it. It is, of course, the discreteness of WHAM that made this procedure so natural (as when three forward steps yield three "" dumps), and the lack of a record of commands was very much an advantage. The children traced with their eyes the path taken by the NAKI; this extended the scope of the projective tasks.

The `Life' lesson involved a NAKI which obeyed the commands N for North (Up), S for South (Down), E for East (Right), W for West (Left)—the same as used in map-reading. The NAKI in Life drew by marking (or 'stinging') its current location with a star when given the command L (`create life'). It may seem surprising to have employed a NAKI that directly obeyed commands essentially relative to the child in this module. However, the child was required to appraise the location of the NAKI in relation to increasingly more complex patterns, also demanding projection.

Of course, more than projection was explored in the lessons. The module incorporated an introduction to the algorithmic aspects of OZNAKI, including WHAM calculator mathematics, some geometry, music and a brief but purposeful introduction to some problem-solving ideas.

Evaluation Programme

How does one evaluate the education robotics developed by the OZNAKI Project? Essentially there are two (intersecting) forms of evaluation. Typically, education 'systems' (broadly conceived) are evaluated on a behaviourist basis: the child is conceived as some sort of black box, of unknown and unknowable inner structure, and the difference in behaviour (equated to class-marks and the like) is measured before and after exposure to the system.

In contrast, the OZNAKI Project is concerned with the difficult task of defining cognitive goals. To specify a cognitive objective, we must state a set of changes we want to bring about in the child's cognitive processes. Thus we are inherently concerned with the inner structuring of knowledge where the 'inner' is the contents of the behaviourist's black box.

In more familiar language, the OZNAKI Project is far more concerned with understanding than merely with *performance* of mathematical tasks. We intend to use thorough-going studies to determine whether such understanding exists. Thus we are concerned not only with the *answer* given to a particular problem, but also with the mental algorithm of *process* used to derive that answer.

It is in this general philosophic framework that studies of the OZNAKI Project were conducted in 1977. In the 1977 evaluation study we sought to examine enhancement of spatial abilities. We focused on projection ___ the ability to 'see' with one's mind's eye from elsewhere __ this having been demonstrated by Piaget as a major process in spatial thinking.

The first trials of OZNAKI involved teaching children from Nillumbik Co-operative School. Evaluation at that stage was informal and based essentially on anecdotal data, although critical observations about the lesson material were made. In September 1977 our first fully fledged field trials commenced in four state schools near La Trobe University. The experimental plan involved Piagetian interviews, multi-choice questionnaires, statistical analyses of data, the subjects being 8- to 13-year-olds.

Future Development of OZNAKI

A detailed account of the 1977 Evaluation Study of the Projection Module is given elsewhere (Cohen & Green, 1978). In sum, the results derived from this study were dramatic. Following a course of just eight lessons in OZNAKI, children gained remarkable improvement in spatial skills.

That such good results can be achieved with such short exposure to OZNAKI highlights the importance of the Projection Module as a paradigm for the development of other courses of instruction involving computer embodiment of mathematics. In all phases, the hardware/software, and the lesson structure, the module was designed with definite cognitive goals in mind. Having definite objectives, it was possible to measure effectiveness in reaching these objectives.

There are also important future applications of OZNAKI concepts and technology to special education. A series of screen 'games' have been designed in which the basic commands model IN/OUT, UP/DOWN, FAST/SLOW, BIG/SMALL, LEFT/RIGHT and other spatial concepts. Other OZNAKI 'games' previously developed for pre-school and primary school students are also relevant to special education such as the PLUSMINUS for presenting the most basic ideas of numbers and mathematical tasks. We intend to use thorough-going studies to determine whether such understanding exists. Thus we are concerned not only with the *answer* given to a particular problem, but also with the mental algorithm of *process* used to derive that answer.

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References

Number Concepts

Gelman, R., 1972. 'The Nature and Development of Early Number Concepts', in Reese, H.W. (ed.), *Advances in Child Development and Behavior*, Vol.7. Academic Press: New York.

Gelman, R. and Tucker, M.F., 1975. 'Further Investigations of the Young Child's Conception of Number', *Child Development* 46: 167.

Spatial Perception and Geometry

Gould, P.G. and White, R., 1974. *Mental Maps*. Pelican Books: England.

Piaget, J. and Inhelder, B., several edns. *The Child's Conception of Space*.

Piaget, J., Inhelder, B. and Szeminska, A., 1968. *The Child's Conception of Geometry.* Basic Books: New York.

Conservation Concepts

Cohen, H.A., 1975. 'The Art of Snaring Dragons', *Memo 338*. M.I.T. Artificial Intelligence Laboratory: Cambridge, Mass.

Multiple Embodiment

Dienes, Z.P., 1958. *Building up Mathematics*. Hutchinson: London.

Logo

Bamberger, J., 1974. 'What's in a Tune', *LOGO Memo No. 13*. M.I.T. Artificial 1ntglligence Laboratory: Cambridge, Mass.

Papert, S., 1971. 'Teaching Children to be Mathematicians vs Teaching About Mathematics', *LOGO Memo No. 4*. M.I.T. Artificial Intelligence Laboratory: Cambridge, Mass.

Papert, S., 1973. 'Uses of Technology to Enhance Education', *LOGO Memo No. 8*. M.I.T. Artificial Intelligence Laboratory: Cambridge, Mass.

Smalltalk

Goldberg, A. and Kay, A., 1976. *Personal Dynamic Media.* Xerox Palo Alto Research Center Report.

Kay, A., 1977. `Smalltalk' *Scientific American* (September).

OZNAKI

Cohen, H.A., 1976. 'The OZNAKI Robotics Language OZ', *Proceedings of the 7th Australian Computer Conference:* 128-143.

Cohen, H.A., 1977. `Micro-Computers for Mini-Mathematicians', in Murray, L. (ed.), *Meaningful Mathematics.* Mathematics Association of Victoria: 391-397.

Cohen, H.A., 1978. `OZNAKI: A New Medium for Mathematicians', in Williams, D. (ed.), *Learning and Applying Mathematics*. Australian Association of Mathematics Teachers: 274-283.

Cohen, H. A., 1979. *OZNAKI and Beyond,* Proceedings of NECC 1979 National Educational Computing Conference, The University of Iowa, Iowa City: 170-178.

Cohen, H.A. and Green, D.G., 1977. 'Teaching Mathematics with OZ-Graphics', *Peoples Computers* 6 (3): 52-58.

Cohen, **H.** A. and Green, D. G., 1978. 'Evaluation of the Cognitive Goals of OZNAKI: Enhancement of Spatial Projective Abilities', in Wildberger, A. M. and Montanelli, R. G. (eds.), *Evaluation of the Use of Computers in Instruction,* Association for Computing Machinery, Special Interest Group on Computer Uses in Education, (ACM SIGCUE), New York: 69-90.

Life

Cohen, H.A., 1978. 'The OZNAKI "Life" ', *Dr Dobb's Journal of Computer Calisthenics and Orthodontia* 3 (4): 10-11.

Gardner, M., 1971 and 1978. 'Mathematical Games', *Scientific American,* February 1971 (pp. 112-117) and October 1971 (pp. 120-123).

Education and Evaluation

Carroll, J.B., 1974. 'Psychometric Tests as Cognitive Tasks: A New Structure of Intellect', in Resnick, L.B. (ed.), *The Nature of Intelligence.* Lawrence Erlbaum: Hillsdale, N.J.

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