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EVALUATION OF THE COGNITIVE GOALS OF OZNAKI

Enhancement of Spatial Projective Abilities

Harvey A. Cohen and David G. Green,
Mathematics Department,
La Trobe University,
Bundoora Victoria Australia 3083

ABSTRACT

The OZNAKI Project applies cognitive goals to the design of TINY robotics languages and sequences of lessons in which students program simple robots and TV "block" graphics. One such lesson sequence, the "Projection Module", has been designed to emphasise "projection", a fundamental spatial ability. The course was evaluated in a study involving students aged 8 to 13 years. Experimental and control groups consisted of students matched by age, class,and spatial ability (measured by pre-test), with no previous OZNAKI experience. While the experimentalgroup participated in OZNAKI lessons the control group had only their usual maths lessons.The pre- and post-tests took the form of individual Piagetian interviews with the primary school students,and multi-choice questionnaires with the junior high school students, thus giving two distinct studies. Significant enhancement of spatialabilities was found for the experimental group in both the primary and the secondary studies.

1.0 INTRODUCTION

The OZNAKI Project is an education research project concerned with the use of microcomputer robotics controllers to provide embodiments of basic mathematical concepts. For OZNAKI, mathematics is conceived broadly so as to encompass general problem solving techniques, formal languages and logic, in addition to the usual number and quantity ideas, algebra and algebraic structures, algorithms, geometry, and spatial relations. From a computer science perspective, the project is concerned with implementing a class of TINY robotics languages on microcomputers and single-chip computers to help primary and junior high school students program simple robots, music synthesizers, and TV "block" graphics.

From an educational viewpoint, the project is notable in that cognitive goals have directed both the design of the basic teaching systems and the content of the teaching modules, which are the

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ultimate target of the OZNAKI Project. Consistent with this philosophy is our use of psychometric tests to evaluate how well the designed teaching and lesson modules meet the cognitive goals. Although the OZNAKI Project shares the use of robots in common with other computer-based educational systems (see Papert, 1973; Goldberg and Kay, 1976), other projects have not tried to meet specific educational needs in the way described above.

This paper explicates our design philosophy through a discussion of one particular teaching module and an evaluation study of that module. In fact the evaluation study described was the first undertaken following the development of the microprocessor based portable systems ("WIZARD BOXes"). Although hindsight shows that there were some details of the evaluation study that warrant revision, we are satisfied that this piece of research has established a paradigm for the OZNAKI Project.

One of the Project's goals is the enhancement of spatial abilities. Although spatial abilities are vital for mathematical competence, no explicit instruction is given in conventional teaching. The ability to imagine how visual images appear from different perspectives is termed "PROJECTION" by Piaget and others.

The link between the discovery of the rules for spatial projection in art and the foundation of modern mathematics in the renaissance has been recounted in many histories of mathematics. What is not as well appreciated is the connection between the development of a person's spatial abilities and other mathematical abilities (Smith, 1964). One of the authors (Cohen, 1975) in a study of problem solving in physics, showed spatial-linked ideas pervading the heuristics central to problem solving in this domain. The Russian Krutetskii (1976), in studies of school children solving conventional maths problems, showed that spatial abilities play a key role.

In 1913 Charles Trowbridge noted that some people in a city always seemed to have a good sense of orientation, while others '...are usually subject to confusion as to direction when emerging from theaters, subways, etc. " (Quoted in Gould and White, 1974). It is clear, as Trowbridge recognised, that a person with mature orientation abilities can change the viewpoint of the informal mental maps in his mind.

Piaget and Inhelder (1964) have described the child's concept of space essentially as follows. For the younger child, space relates to himself as focus (is egocentric). Topological relationships, but not metrical relationships, are recognised. In seeking to understand how the child's views of space develop, Piaget's comments are of special sigificance: "...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 link between the topological, egocentric view of the young child and the Euclidean view of formal reasoners.

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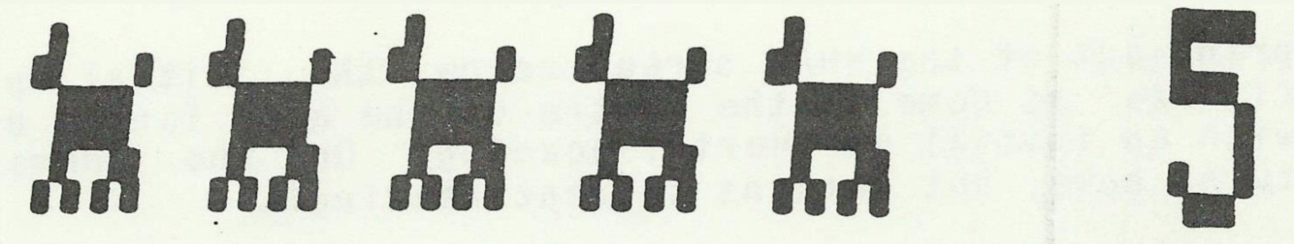
Trowbridge made interesting suggestions as to how the class teacher might promote spatial skills. Mc F. Smith, gave historical and other evidence for the role of spatial ability, but did not propose any specific training. The authors know of no properly evaluated teaching scheme directed at spatial abilities.

2.0 OZNAKI = COMPUTER EMBODIMENT OF MATHEMATICS

In this and the following subsections, a general introduction is given to OZNAKI, to place in some perspective the teaching unit called the Projection Module.

The simplest OZNAKI system is the PLUSMINUS. A keyboard with just two large keys, marked with the "+" and "-" symbols, which emit audible clicks, is used with the PLUSMINUS. Each time the + key is struck one more animal appears on the display screen and the number display is incremented accordingly.



The PLUSMINUS commands (+ and -) effect a modelling of the operations of addition and subtraction. Conventional materials, such as those of Dienes (1958), can only model the "before" and "after" of such an arithmetic operation. The significance of these operations in the development of the child's understanding of number has been stressed by Gelman (1972, 1974).

OZNAKI involves a family of tiny languages in which a core set of commands is modifiable by numbers and "mode" characters. Thus typical commands are "6+", meaning add one six times (to a number display), 4HF, meaning take four steps forward, while "honking". In all except the simplest languages a run time macro facility is available, so that a single character stands for a user-defined string of commands. A rather unusual way has been developed to pass numeric parameters to macros via visible accumulator(s). Conditionals in OZNAKI are symbols that take the value zero or one, and so effect the following bracketed command list.

The OZNAKI languages program the activities of robots called NAKIs which are conceived as possessing both a "body" and a ""mind". As the "mind" includes user-defined and built-in macros, and other data, a NAKI is very much like a SmallTalk class instance. However OZNAKI involves TINY systems, implementable on the second generation of microprocessors, the 8080 and 6800 processors in from 200 to 2000 bytes.

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2.1 WHAM

In WHAM the student commands a NAKI called Ozzie whose mind and body are both visible on a TV\ screen. Depending on where Ozzie is heading, the body of the NAKI is either a A, >, V, or <. On the command R Ozzie turns clockwise ("right") through ninety degrees. On the command F the NAKI advances one step in the direction of his heading, leaving (in trail marking mode) an asterisk. A string of commands is displayed as keyed in, but not actually obeyed until terminated with the <Do-It>, which appears on the screen as a "!".

The body of the NAKI is restricted to the left of the screen, while the mind is to the right. In Ozzie's mind is the current command plus the current definition of the four user-definable macros V, W, X, and Y. The command Z followed by the macro name and then a list of commands, terminated by the <Do-It> places the new macro definition in the Mind.

Also demarcated on the screen is the number display of a reverse-Polish calculator. The number in this calculator has the name A.

In the print-out of the WHAM screen below, the initial position of the NAKI was at Home in the centre of the area fenced off with "+" signs, with an initial up (North) heading. On the command J, the NAKI returns home, but retains current heading.

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

Combining WHAM calculator arithmetic with the NAKI movement commands yields a numerical geometry which includes not only squares and rectangles, but also several forms of spiral.

```
+ + + + + + + + + + + + + + +  +
+                              +
+                              +   V =
+     * *  * *  * * * * * * >  +
+     *                        +   W=
+     *   * * * *   *  *       +
+     *   *              *     +   X= AF R 1+
+     *   *    * *       *     +
+     *   *      *       *     +   Y=
+     *   * * * *        *     +         + + + + +
+     *                  *     +         +       +
+     *  * *  *  * * * *       +         +  10   +
+                              +         +       +
+                              +         + + + + +
+ + + + + + + + + + + + + + +  +   10X !
```

In the above "squiral", the NAKI set out from from a central Home with an initial heading upwards, and with accumulator A zero. On the first X, Ozzie, turned right, and A became one. Following each incrementing of A, a longer arm was drawn, making 10 arms in all (the first of zero length.)

2.2 ZONKY

The OZNAKI Project has developed several ambulatory robots each called ZONKY. The command language called OZ in (Cohen, 1976) has been somewhat modified and renamed TINMAN. The actual ZONKY used in the experiments described here is of circular plan, with the directions for right and left turns (about the central axis) actually marked.

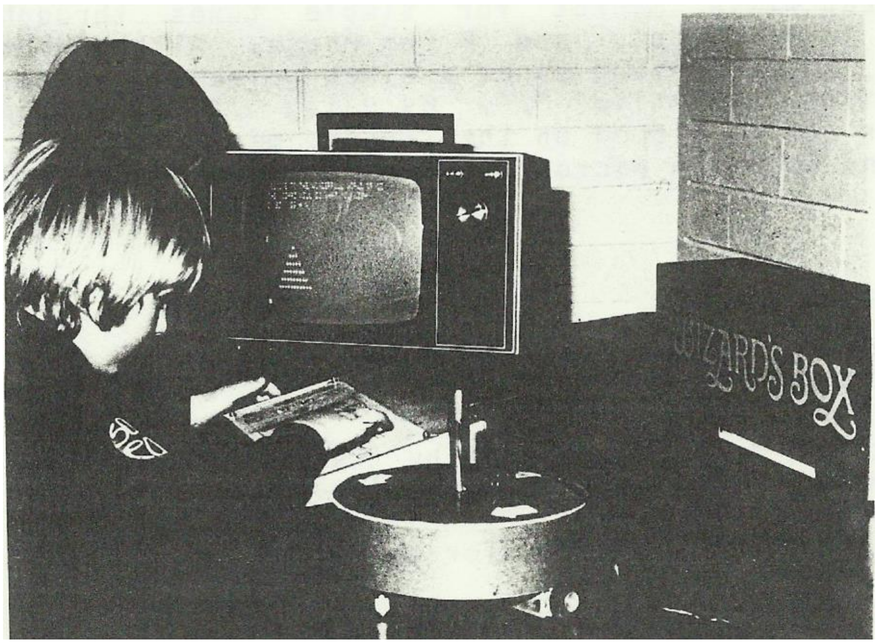

Figure 1. Two students, the robot ZONKY, keyboard and microcomputer.

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The basic commands for ZONKY are "F" for forward, "B" for backwards, "R" for right, and "L" for left. While performing these movements the automaton can also be ordered to honk "H", and (a)light its lights "A". "J" is the command for ZONKY to "sing" the first bar of the tune "Jingle Bells". A string of commands - like an English command - must be terminated by an exclamation mark "!" To illustrate, following the command 3AF 2HR ! the robot makes 3 steps forward with its lights flashing, then makes 2 turns right (clockwise) on the spot whilst honking its horn. In between each forward step or unit turn there is a one second delay. While on the TV screen the commands punched in by the student are visible. Also displayed are the actual control words that are directed at ZONKY. Thus for the student commands

3HF 2AR

a further embodiment of number is supplied through the display on the screen of the ZONKY language words:

aaaaaaaaaa aaaaaaaaaa aaaaaaaaaa gggggggggg gggggggggg

Note that corresponding to a unit motor command, there are precisely ten lower case control characters displayed. This facilitates the introduction of decimals.

The string of commands 3AF 2HR ! could be called X (or otherwise V, W, or Y) by punching in

ZX 3HAF 2HR !

The command C causes ZONKY I to emit a Clang sound. Hence if a child punches in ZX 3C ! he will hear six clangs on the command 2X ! .

Students can write macros for simple tunes through use of the commands T for Toot, and P for Pause. Although only one note is available, the resulting tunes are recognisable. Finally we mention the printing primitive "/". By using "/", very simple patterns of characters can be formed on the screen, messages can be printed by macros, and built-in macros such as F can be duplicated.

3.0 THE PROJECTION MODULE

The Projection Module developed by the authors comprises just eight lessons, which are detailed in the Appendix.

ZONKY and WHAM involve NAKIs for which the basic commands - FORWARD,

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BACK, RIGHT, and LEFT, relate to the NAKI's current heading - not to the student's egocentric frame. To direct these NAKI's inherently requires projection.

Following Piaget's dictum, "... spatial concepts are internalised actions" in the first lessons with ZONKY pupils are encouraged to play out NAKI moves as directed by another pupil. Included in the lessons are the tasks of guiding ZONKY past obstacles, and a similar, but more demanding maze with the WHAM NAKI. The pupils are asked to punch in as many commands as possible before telling the NAKI to "Do-It".

In WHAM, students are encouraged to first 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 makes this procedure so natural, and the lack of a record of commands is very much an advantage.

The final lessons are on a microcomputer "Life", which is an enhanced version of that described by Cohen (1978a). The "Life" NAKI obeys the commands N for North (Up), S for South (Down), E for East (Right), W for West (Right). On the command L the cell visited by the NAKI is made live, while K kills that cell. Students are asked to copy onto the screen patterns of live cells, visible as asterisks, before initiating the Life process. (Martin Gardiner, 1970).

Of course, more than projection is taught in the lessons. They also include an introduction to the algorithmic aspects of OZNAKI, including WHAM calculator maths, some geometry, music, and a brief but purposeful introduction to some problem-solving ideas.

It is generally envisaged that the Projection Module will involve one or two students using a single OZNAKI system within an open class-room, or a complete class of say 24 students with one Wizard's Box for every two students. During the evaluation study between four and six children were taught by a single tutor (D.G.G.), using just one microcomputer Wizard Box.

4.0 EVALUATION PROGRAMME

How does one evaluate the educational robotics developed by the OZNAKI Project? Essentially there are two (intersecting) forms of evaluation. Typically, educational "systems" (broadly conceived) are evaluated on a behaviorist basis: the student is conceived as some sort of black box, of unknown and unknowable inner structure, and the difference in behavior (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 student's cognitive processes. Thus we are inherently concerned with the inner structuring of knowledge - where the "inner" is the contents of the behaviorist'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 or 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 full-fledged field trials commenced in four state schools near La Trobe University. The experimental plan involved Piagetian interviews, multi-choice questionnaires, and statistical analyses of data - the subjects being students 8 - 13 years old. The Projection Module provides a general introduction to OZNAKI mathematics, with heavy emphasis on spatial skills involving projection.

4.1 EVALUATION OF THE PROJECTION MODULE

The evaluation study carried out in Spring 1977 had the following phases:

(a) Pretesting of all students involved.
(b) Selection of Experimental and Control Groups.
(c) Teaching the Projection Module to the Group.
(d) Post-testing of both E and C Groups.

The students participating in the study were aged 8 to 13, that is at the stage of development in which projective skills are assimilated. They included both primary and secondary students.

Similar, but distinct, experiments were carried out at the high school and primary schools. Experiment 1 comprised work carried out at three primary schools: Yarraleen, Preston East, and Fawkner

North. Twenty-seven pupils in seven classes completed the course. Each experimental group received two 1-hour lessons per week for four weeks. Experiment 2 comprised work carried out at Montmorency High School. Forty-four pupils were involved. The 22 students in the experimental group received one 1-hour lesson per week for eight weeks. Experiments 1 and 2 also had slightly different testing procedures (see below). D.G.G. conducted the lessons for all classes.

In both experiments, control groups consisted of students paired with individuals in the experimental groups. The pairs were formed by matching together students whose performances during pre-testing were as close to identical as possible. In every case the pairs consisted of students from the same class and of similar age. We tried to reduce the effects of the childrens' normal learning environment (teacher, school, etc.) by selecting our subjects from as many different classes (and schools in Experiment 1) as possible. Primary school subjects were chosen at random from the entire classes available, while the secondary school subjects were all selected at random from the weakest 25% of students (as determined by the pre-test), because of our interest in the use of the Projection Module in remedial education.

Students in the control groups attended normal classes at the times when OZNAKI lessons were conducted. The effect of the course on the experimental group's ability to project was assessed by comparing their performance in post-test exercises requiring projection with the performance of their counterparts in the control group.

4.2 DESCRIPTION OF THE TESTING PROCEDURE

At both the primary and high schools, all the students involved were tested both before and after presentation of the course of lessons. Testing of the primary school children involved a Piagetian type interview, whilst testing of the high school students was conducted by written, multi-choice questionnaires.

EXPERIMENT 1

Three games were presented to the primary school children in their interviews. The same games were used in both the pre- and post-tests.

Game 1 - The Mountains"

A model of three mountains was placed before the child. The interviewer produced sketches of various views of these mountains, and asked the child to place a toy man at the spot on the model from where each view could be seen. To obtain a performance parameter, the interviewer noted the time taken in each placement. Pupils scored one mark each time they placed the model man in the correct position. The Mountains is a classic test due to Piaget and his collaborators (Piaget et al, 1956, Piaget et al, 1960). In our presentation, subjects were permitted to walk around the model. Clearly the subject could solve this task by projection. However by standing behind the toy man the subject could gain nearly the same perspective

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Game 2 - "Remote Driving"

This test was designed by H.A.C. as a test whose solution requires projection, and involves everyday language and experience. The subjects were confronted with a large town plan (bare of buildings) with a rectangular grid of roads, and a "match-box" car. The children were asked to: (1) follow instructions (turn left or right) given by the interviewer, while "driving" the car about the streets of the town, keeping to the left of the centre line - this was scored on whether they made correct turns and whether they kept the car on the correct side of the road; (2) After being shown a particular route around the streets of the town plan, the subjects gave the interviewer instructions for following the route by car (that is, how many blocks to go ahead and directions of turns) - one mark was scored for each correct answer. Both parts of the test demanded that the students work out directions for the car to turn for all possible orientations of the car relative to the subject.

Game 3 - The "Left Handed Route"

This test involves the use of the model town and toy car described above. In this game, the child was asked to plan a path requiring left turns only between two given points in the town and to "drive" the toy car around this path - pupils were scored simply as successful, if they found such a path, or as failed otherwise. This test could be described as a problem of planning in a spatial context.

EXPERIMENT 2

At the high school, to select the students to participate in the course, and a matched control group, we tested four complete seventh form classes using an ACER "Spatial Abilities" Test. Experimental and control group pairs were selected from the students with lowest scores on the test, by matching pupils who had both the same score and made similar sorts of errors. As in experiment 1, all pupils paired together came from the same class.

Pre-Test/Post-Test:"ACER Spatial Abilities Test"

The Australian Council for Education Research (A.C.E.R.) has developed a question bank containing a collection of multi-choice answer questions involving spatial abilities mixed variously with elements of problem solving (Cornish,1977). For instance, one outline sketch shows two footprints at skew angles, and the question is whether these are two left feet, two right feet, or otherwise. We

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prepared two printed questionaires both of twenty questions from these A.C.E.R. questions. One A.C.E.R. derived questionaire was used with high school students both as the pretest and in selecting experimental and control group pairs. The other questionaire was included in the post-test for high school students.

Post-Test:"The Mountains", "Remote Driving", "The Left Handed Route".

The high school students were subjected in the post-tests to isomorphs of the problems posed to the primary children: that is, they were given exactly the same questions as the primary pupils, but in a written form instead of orally, and they marked their answers on diagrams on the test paper. The printed version of the Mountains Game was closer to the classic Piaget interview in that the three model mountains were given distinctive colours.

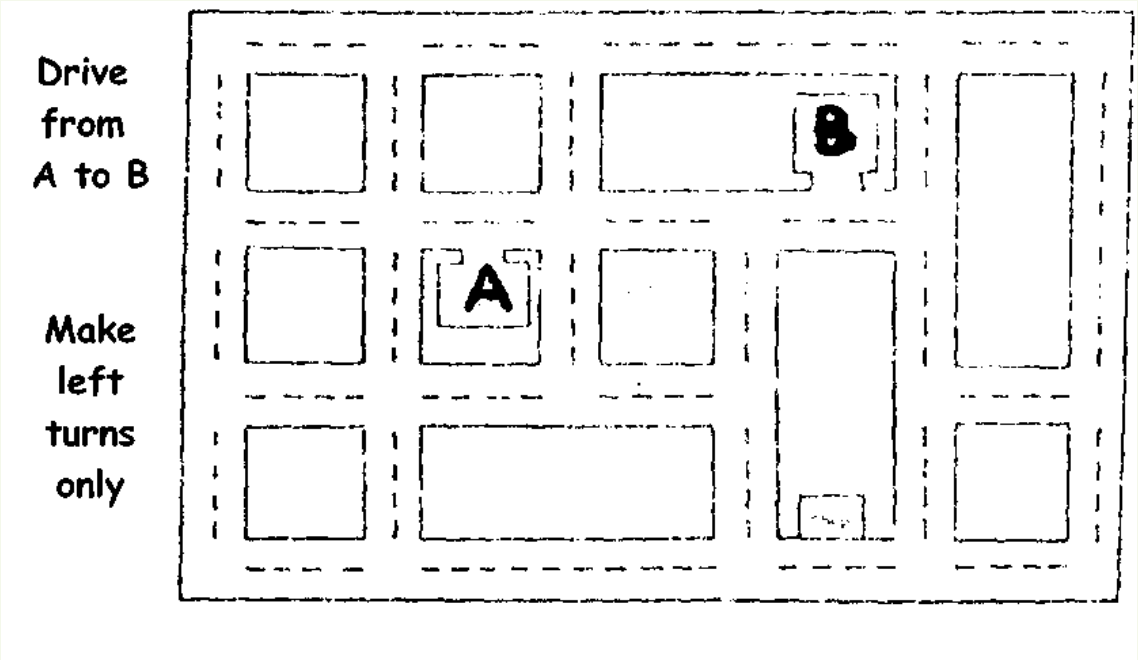

Figure 2. The town map used in the High School experiment (reduced in size). Subjects were asked to mark the path they would take in driving a car from carpark A to carpark B making left-hand turns only.

4.3 TEST RESULTS

EXPERIMENT 1 PRIMARY SHOOLS

Game 1 - "The Mountains"

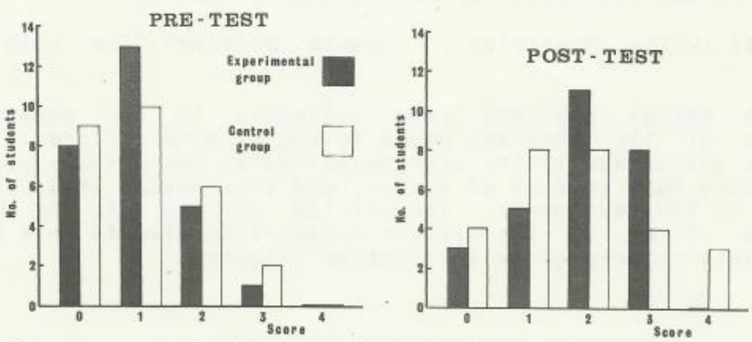

Figure 3. Score distributions in the "Mountains" Test for the primary school pupils.

Game 2 - "Remote Driving"

Table 1 presents means and standard deviations for the score distributions of the experimental and control groups in both pre- and post-testing. One-way analyses of variance were performed to test the significance of the differences in scores (Anderson,1958; Nie et al. 1975). The probabilities resulting from an F test are tabulated: they show the probability that the differences in recorded scores did NOT occur by chance.

TABLE 1

Analysis of Pupils' Mean Scores on Remote Driving Test

	Max possible	E Group	C Group	p
Pre-test	21	12.3 (2.7)	13.1 (3.0)	0.656
Post-test	21	17.9 (2.6)	14.7 (3.9)	0.999
p		1.00	0.916	

Notes:
1. There were 27 pupils per group
2. Numbers in brackets are standard deviations of the Score distributions about the given mean value
3. Values tabulated for p are the probabilities that the differences between the given means did NOT occur by chance.
4. A two-way analysis of variance on the results in the table showed that the significance of the interaction of group and test effects was p = 1.00

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Game 3 - "Left-Handed Route"

Table 2 shows the numbers of pupils in each group who solved the "Left-Handed Route" problem in pre- and post-tests. The improvement shown by pupils in the experimental group was so huge that to test its significance is pointless.

The average times taken to solve the problem (by the successful students) in pre-testing were 2- minutes 36 seconds for the four experimental group students and 1 minute 41 seconds for the four control group students. In post-testing, the four experimental group students who solved the problem initially all improved their times (average 1 minute 30 seconds). Only one of the four control group students who solved the problem during pre-testing could again solve it during post-testing.

TABLE 2

Numbers of Pupils Solving the "Left-Handed Route" Problem

	Experimental Group	Control Group
Pre-test	4	4
Post-test	21	3

Note: There were 27 students in both groups.

EXPERIMENT 2 HIGH SCHOOL

Table 3 below lists means and standard deviations in the same way as for game 2 above. One-way analyses of variance were again performed on the data and the resulting significance levels for the differences in experimental and control group scores are tabulated. The two ACER space tests used were not of identical difficulty, so the pre- and post-test scores of each group are not strictly comparable (so only one analysis of variance has been performed.) On the "Left-Handed Route" problem, 10 experimental group students and 8 control group students were successful.

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TABLE 3

Analysis of Scores on High School Tests

	Maximum Possible	Scores Group	Group	p
Pre-test: "ACER Spatial Abilities" no.1				
	20	8.95	9.23	
		(2.03)	(1.82)	
Post-test: "ACER Spatial Abilities" no.2				.353
	20	10.77	9.32	
		(2.91)	(3.13)	.886
Post-test: "The Mountains"				
	4	2.95	2.36	
		(1.13)	(1.26)	.895
Post-test: "Remote Driving"				
	16	13.86	10.36	.997
		(3.18)	(4.02)	

Notes:
1. Each group contained 22 pupils (44 in all).
2. Numbers in brackets are standard deviations of the score distributions about the given means.
3. Tabulated values of p are probabilities that the differences between the given means did NOT occur by chance.

4.4 DISCUSSION

The principal cognitive goal of the Projection Module is enhancement of projection ability. This we seek to measure by examining skill in particular spatial tasks. There are spatial tasks that are expeditiously solved using projection. However in many such tasks there are alternate algorithms not primarily based on projection. Thus in everyday life, many people with most inadequate projective ability successfully use road maps, by rotating the map until the section of road they are approaching is straight ahead. In contrast, a person with good projective ability, can crawl (in his/her mind) along the streets on the map, irrespective of their heading.

The Remote Driving test is probably the best measure available of "pure projection". However, in this test a good score could be achieved by learning a set of "rules of thumb", such as the following: "if coming from the right (of the plan relative to the viewer) then a car turns right to go directly away."

In both the primary school and high school experiments, there was significant improvement in Remote Driving score. In the primary experiment, where Remote Driving was used as both pre-test and post-test, significant enhancement was apparent both by comparing the experimental group before and after, and by comparing experimental and control in post-test. The results also show that with the primary school children, the experimental group was marginally inferior to the control group at remote driving in the pre-test.

The "Left-Handed Route" problem is not a test purely of projective ability, as some measure of planning skills are involved. In the pre-test, only 4 control group pupils and 3 experimental group pupils completed the task entirely correctly; in the post-test 21 of the experimental group of 27 were successful, versus 3 of the control group (also of 27). With an increase of this magnitude, the application of statistics is indeed frivolous: one can assert with confidence that the improvement was large.

Given the success of our primary school experimental subjects on the "left-handed route" problem, we naturally anticipated similar success by the high school subjects. However, when tested, our high school experimental group performed only slightly better than the control group (10 successes versus 8). Since the experimental group had already demonstrated its greater ability at projection on the remote-driving test, this insignificant difference warrants some informal observations. In presenting this test along with others, it was not possible to ascertain whether failure to complete the task was because of lack of time or of inability. And was the inability due to lack of understanding of the written question, rather than of the abilities needed in solution?

The score distributions of the primary students in the Mountains test is presented in Figure 3. The subjects in the experimental group performed marginally better overall on the mountains puzzle than their control group counterparts. Only four particular questions were asked and there was a large spread in performance with the average score about 1 out of 4 correct in pre-testing. On the post-test, the average score was nearer 3 for both groups. The somewhat greater improvement of the experimental group was not statistically significant, masked as it was by the pronounced training effect. Note our remarks above re the use of pure projection versus other means to solve the Mountains task. It is indeed likely that repetition provides opportunity for subjects to discover solution algorithms alternate to projection. In the high school experiment, where a printed version of the Mountains was used only in the post-test, the experimental group was significantly superior (at the 10% confidence level).

The ACER spatial abilities tests were a pot pourri of questions, not specifically tailored to testing projection. The improvement of experimental group over control was of statistical significance at (about) 10% confidence level. Had this test not been included in the post-test, the number of questions included in the high school Mountains, Remote Driving, and Left-Handed Route could have been greatly increased, reducing the variance of the test scores.

Poor reading comprehension obviously did affect the scores on the printed tests given to the high school pupils. We suspect that lack of comprehension may have been involved in a few cases of well-nigh failure amongst the primary school children too. About one third of the experimental group consisted of migrant children. While all of them were apparently fluent english speakers, improvement was generally lower than for the rest of the experimental group.

In allotting high school students into E and C groups the students were first paired. To select which student in a pair went into the E group, it is clear (from ACER No 1 scores) that we tended to put the weaker of the pair into E. A better match of E and C would have been achieved by tossing a coin to make that selection. A bigger sample size would have enabled separate study of (non-English) migrants and would aid in untangling the other factors applying in Experiment 2.

In the experiment 2, only the total score in the ACER test has been subjected to analysis. However it is possible to unambiguously classify some of the questions included in the ACER tests as involving Topology, Reflection, or Rotated Figures Recognition. Other questions admit of a less ambiguous classification or else involve these skills in combination with other problem-solving factors. Such a question classification could be used to extend the above analysis of the high school experiment.

One must beware of reaching hasty conclusions as to the impact of the Projection Module on students of different age groups. The primary students involved in experiment 1 were of average ability. However our high school subjects were chosen amongst the weaker students in their classes. Nevertheless it is tempting to speculate whether the younger child at the Piagetian concrete operational stage can in general gain more from such an experience as the Projection Module.

Our use of psychometric tests in assessing cognitive change is consistent with current trends in cognition (Carroll, 1974; Resnick, 1977). Cronbach et al (1970,1974) have presented discussions of experimental design especially relevant to studies applying this strategy. In the conduct of Experiment 1, the same tests were used for both pre- and post-tests. This aspect of design was essentially superfluous, as in comparing improvement we had available experimental and control groups, but saved us from the need to devise other tests or criteria (class marks in maths etc) to select experimental and control group members. The situation re the Mountains test in Experiment 1 is well brought out by the plotted results in Fig 3. There was a pronounced training effect, which masks any improvement. The variance was also increased by the small number of questions asked. It is clear that this test is one whose reliability would have been improved by restriction to the post-test.

4.5 CONCLUSION

In a course of just eight lessons with OZNAKI, children have demonstrated pronounced improvement in projection. In spatial tasks generally the comparative improvements were sufficiently consistent that, despite the small sample sizes involved (22 or 27 in each of the various distinct groups), statistical analysis confirms that conclusion.

That 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.

Where does the OZNAKI Project go from here? Other teaching modules have been conceived to include such topics as properties of number, ideas of algebra, permutations, lattices, symmetry, patterns, and tune blocks. For such modules, the experiments described in this paper give a model for evaluation. In addition it would be desirable to conduct further studies on students who have had considerable involvement in OZNAKI.

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APPENDIX

SYLLABUS OF THE PROJECTION MODULE

LESSON 1

(a) Introduction to WIZARD's BOX, ,ZONKY, and the symbol/command idea.

(a) Pupils take turns at imitating the NAKI while the others guide them around obstacles. They are taught to repeat this game whenever they have trouble working out directions for ZONKY etc. (c) Guiding ZONKY around an obstacle course, giving it as many commands at one time as possible.

LESSON 2

(a) Students teach each other how to "walk around the table" (knowing initially how to go forward, back, right, and left only).

(b)Discussion on how we learn:the pupils are shown how they translate a simple parental command, such as "get up and go to school", into a complex series of learned routines (e.g. dressing, having breakfast). (c) Teaching ZONKY how to draw closed figures.

LESSON 3

(a) Pattern-drawing with ZONKY (polygons, circle). Attention is given to the relation between the commands given and the path ZONKY draws, emphasizing that patterns always result from repetition of the basic algorithm "forward and turn". They discover, in the process, that the smaller the turn on each repetition, the greater is the number of sides in the resulting polygon - thus showing a circle to be like a polygon with many sides - and that increasing the step length on repetitions of an algorithm produces a spiral.
(b) Creating new patterns by altering existing routines (e.g.zig-zag).

LESSON 4

(a) Music with ZONKY: creating rhythms and simple tunes.

(b) Drawing simple patterns on the screen with OZ: e.g. Xmas tree.

(c) Problems involving music and screen drawing.

LESSON 5

(a) Running mazes with WHAM. One command at a time. Two. Three. As many as possible before the <Do-It>.
(b) Use of macros.

LESSON 6

(a) Pattern-drawing with WHAM (squares, crosses, squiral, etc), involving iteration of just one macro command. (b) Introduction to WHAM calculator. Simple numeric algorithms.

LESSON 7

(a) Discussion on the problem-solving methods learnt and their application to other activities. These methods include the "divide and conquer" approach to complex problems and the "debugging" concept. (b) Introduction to LIFE. (c) Drawing elementary LIFE patterns (e.g. line, glider).

LESSON 8

(a) Harder patterns in LIFE (e.g the glider gun). (b) Students experiment with their own patterns, (c) Revision of the whole course with selected problems and challenge mini-projects (e.g. drawing complex patterns).

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