# Scientific enquiry. The nature and place of experimentation. Part 2

# Investigación científica. La naturaleza y el papel del experimento en clases. Parte 2

NORMAN REID[1] AND LEKOKO SERUMOLA[2]

Centre for Science Education, University of Glasgow, Scotland, UK[1]; University of Botswana[2]
N.Reid@mis.gla.ac.uk

***Abstract***

*Most school syllabuses, even those for primary stages, specify aims that relate to the use of experimental work in gaining evidence. The paper describes a series of experiments in Botswana and Scotland with pupils aged 12-15 which aimed to measure the attainment of such outcomes and the development of such outcomes by targeted teaching. A first experiment surveyed 330 Botswana school pupils. This was followed by a study of 752 Botswana school pupils where 342 were exposed to teaching materials aimed deliberately to encourage the development of such skills, the remainder being taught normally. The assessment procedures were repeated with 741 Scottish pupils of the same age and, finally, 120 Scottish pupils were taken through the game, "Eloosis", this exercise being described as a model of scientific thinking in terms of understanding the role and nature of experimentation. The skills are explored and evidence is discussed that suggests that such aims might be difficult to attain with younger secondary school pupils simply on grounds of cognitive development.*

***Key words:*** *empirical, critical experiment,, critical experiment, scientific thinking, scientific literacy.*

***Resumen***

*La mayoría de programas escolares, incluso para la educación primaria, especifican propósitos que se relacionan con el uso del trabajo experimental en ganar evidencia. El artículo describe una serie de experimentos en Botswana y Escocia con alumnos de 12-15 años para medir el desarrollo y el logro de tales resultados. Un primer experimento examinó a 330 alumnos de Botswana. Esto fue seguido por un estudio de 752 alumnos de Botswana donde 342 fueron expuestos a los materiales didácticos dirigidos deliberadamente para animar el desarrollo de tales habilidades, el resto enseñado normalmente. Los procesos de evaluación se repitieron con 741 alumnos escoceses de la misma edad. Por fin, 120 alumnos escoceses practicaron el juego "Eloosis", un ejercicio que se describió como modelo del pensamiento científico en términos de entender el papel y la naturaleza de la experimentación. Se exploran las habilidades y se discute la evidencia que sugiere que tales propósitos pudieran ser difíciles de lograr con alumnos más jóvenes de la educación secundaria, una afirmación basada simplemente en los argumentos del desarrollo cognoscitivo.*

***Palabras clave****: experimento empírico y crítico, pensamiento científico, alfabetismo científico*

## INTRODUCTION

The world wide desire by science educators and policy makers to promote scientific literacy (AIKENHEAD and JEGEDE, 1999; American Association for the Advancement of Science (AAAS), 1989; CHILD, 1993; DRIVER, 1983; HAZEN and TREFIL, 1990; JENKINS, 1990; JOHNSTONE, 1997; MASON, 1962; OSBORNE, 1997; Science Council for Canada (SCC), 1984; School Curriculum Development Committee (SCDC), 1987; Scottish Office Education Department (SOED), 1994; SOLOMON, 2001) is central to the search for effective approaches required for teaching and learning science in schools. Emphasis by some curricula to engage pupils at junior secondary school levels in pupil-planned and pupil-designed investigations raises some concerns about the cognitive ability of those pupils to handle such exercises and produce expected outcomes.

Do pupils at junior secondary levels (approximately 12-15 years old) have the cognitive ability to plan and design experiments which investigate scientific ideas? Can they formulate theories and identify critical experiments to test the theories? Have they covered adequate content material to develop scientific thinking without excessive assistance from teachers?

This paper summarises the findings from three major experiments which tried to explore such questions. The first experiment sought to establish a base-line as to what extent school pupils (in Botswana) are able to conceptualise the place of experimentation in investigating scientific phenomena. Two methods were used:

(1) A card game called Eloosis

(2) A evaluation specially devised for the purpose.

Each is now described.

**Eloosis**

Eloosis is reported to have been used successfully in science courses to teach the scientific method, especially the nature of experimentation in problem solving activities (ZIEGLER, 1974). Some science educators refer to Eloosis as a card game that simulates the scientific method (ZIEGLER, 1974; MATUSZEK, 1995). The intention was to use the game to explore the extent to which pupils had grasped the scientific way of thinking. ZIEGLER (1974), after using the game at high school level, stated:

> *"One topic that occurs in most high school chemistry courses is the scientific method of problem solving. Rather than simply lecturing to the class on the topic this experiment* (Eloosis) *allows the students to uncover the process themselves"*. (p. 532).

Another characteristic of Eloosis is that it emphasizes inductive reasoning or coming up with an explanation that fits the observed facts. This reflects how the game was used in the study.

Eloosis was invented by Robert Abbott in 1956. The primary purpose of the game was to simulate scientific thinking or demonstrate scientific investigations. It involves a leader and one or more packs of ordinary playing cards. The leader shuffles the pack(s) of cards and deals them out until all are gone. It does not matter if some students have one card more than the others. The game works well with groups up to 20 in size.

The students play the cards in turn and the leader either accepts or rejects each card when placed face up on the table according to some 'system' in his/her mind. The system may vary in complexity. An example of a simple system can be: a series of 'a black card followed by a red card' or a series of 'any odd numbered card followed by any even numbered card' and so on. An example of a complex system can be: 'any first two black cards numbered lower than five followed by any red card numbered above five' and so on. The permutations of systems are endless.

Accepted cards are left face up on the table and the task of the students, individually (or together if that is an agreed rule) is to work out the system they may stop the game at any time if they think they have determined the system.

**Data obtained**

A questionnaire was applied one week later to explore their approaches to the game and also offered a test question which sought to explore their ability at *seeing key information to solve a problem*. The questionnaire sought information about the way the pupils preferred to learn and then asked about how they tried to solve the problem posed by the game, seeking to find out what methods they used.

Pupils were then asked to solve a genealogical problem. Firstly, they were given a family tree to complete and then asked to manipulate the information given to work out the grandmother's age. The problem is apparently complex but, if the pupils can see that the key information is the connection between age and date, it is easy to obtain an answer. The problem sought to test if the pupils could spot the key link (rather like a critical experiment) and then draw the conclusion.

The two methods used in this part of the study sought to provide evidence on pupils' conceptualization of the place of experimentation in investigations of scientific phenomena. However, the real problem is to establish the validity of the approach.

A sample of 330 pupils randomly chosen from five lower secondary schools in Molepolole region (Botswana) was involved. The sample consisted of 157 boys and 173 girls taken from years one and two, 148 from year one and 182 from year two, encompassing both characteristics of rural and urban pupils. Classes in Botswana are mixed ability and, within a class, there is a wide range of ability, especially in terms of language proficiency, reading and writing and subject knowledge. Age ranges ran from 12-14.

Pupils showed a lot of enthusiasm in playing the game which sparked much debate amongst members of each group. The researcher observed in many of the instances that the enthusiasm from players came, not as a result of enjoying peer interaction only, but also from the demands placed on their cognitive involvement during play. The two year groups tended to show the same patterns of behaviour. This is consistent with the idea that, in cognitive terms, they are at similar developmental levels when faced with this kind of problem.

23% (year 1) and 19% (year 2) managed to complete the genealogical table correctly while only 13% (year 1) and 5% (year 2) managed to work out the answer.

Pupils were asked to describe themselves and could select as many as they wished of: *I learn better on my own, I learn better when sharing ideas with others, I like solving challenging, I like solving easy activities, I like to take part during group discussions, I like listening to others talk during group discussions.* No relationship was found between their responses in these descriptions and their performance in the genealogical problem.

Pupils were asked to indicate how they solved the Eloosis problems, five responses being offered to them. There was no statistical difference between the year groups (table 1)

**Table 1**
**Solving Eloosis problem**

| | Year 1 | Year 2 |
|---|---|---|
| By guess work | 48 | 44 |
| Observing the pattern of cards accepted by the dealer from others | 47 | 44 |
| Observing the pattern of cards accepted by dealer from me | 40 | 39 |
| Observing the pattern of cards rejected | 45 | 42 |

The genealogical problem sought to offer a test of their ability to look at evidence and see what was the critical feature. This enabled solution of the problem to be straightforward. If this is related to the pupil ability in seeing the critical nature of experimentation in being able to drawing valid conclusions, then this ability is unrelated to age, gender or preferred learning style.

Despite playing the game (where there was enthusiasm, with pupils showing an overwhelming inclination towards group work and sharing of ideas during problem solving), no difference in performance was observed when comparing the two year groups. Perhaps, the test was too hard for them. However, was the skill of 'seeing' critical information or a critical experiment not being achieved by pupils for developmental reasons?

**The next stage**

The next stage was to develop and use some teaching units which specifically sought to teach the skills related to the place of the empirical in thinking and to refine the test. Eloosis would now be used as a *teaching tool* rather than as an investigating instrument. The units were developed to see if it is possible to accelerate the development of this skill by using appropriate teaching.

Pupils were divided into two groups. The experimental group was involved in the teaching units meant to develop the experimental approach strategies. The control group was never exposed to these units but underwent normal school learning together with the experimental group.

Teaching units were based on the contents of the Botswana's three-year junior secondary integrated science syllabus. Instructions on Eloosis used as a teaching tool were designed as well. To minimise factors such as variation in teaching style or experience which might produce an unbalanced delivery of the instructions on the teaching units and the Eloosis, the experimental groups were instructed by the same person at the same time of the day and under the same classroom conditions. To evaluate the effects of the teaching units and Eloosis, two evaluations were constructed, one for the experimental group and the other for the control group. These evaluations were administered to the two groups on the same day under the same instructions by the science teachers who volunteered to help in this project from each of the schools selected. In addition, some pupils selected from the sample groups were interviewed.

A sample of 752 pupils (342 in experimental groups and 410 in control groups) were randomly chosen from four of the five schools in Molepolole (Botswana) used during the first experiment. Each experimental group had two sessions of units teaching and Eloosis (3 hours). The evaluation was applied a week later to both the control and experimental groups from the same school.

### Teaching units

The titles and the main objective(s) of each teaching units are now described.

Unit 1 *Using the Right Metal*: Pupils were expected to use information provided on some characteristics of selected metals to choose the best metal for each described purpose, requiring pupils to identify critical information and design a critical experiment in order to provide a scientifically viable choice of metal.

Unit 2 *Trees and Car*: Pupils were expected to manipulate and use the information given about the carbon dioxide absorbed or produced by trees and cars to determine whether the claims by a newspaper report were credible. The activities required pupils to debate in a group and generate possible ideas that would justify their reasons for or against the newspaper claims.

Unit 3 *Food and Health*: Pupils were asked to use the information provided on the kinds of food required by the human body and their functions in the human body to prescribe a healthy diet for individuals at different ages. The tasks required pupils to identify the critical piece of information necessary to provide a reliable solution to a problem.

Unit 4 *Shadows*: Pupils were expected to use information they gained from school science lessons to design a critical experiment that would provide a scientific explanation for shadows. The nature of the apparatus to be used was described to them. The tasks required pupils to use an experiment as a source of information and identify the critical piece of information necessary for the design of the experiment.

Unit 5 *Ecosystem*: Pupils were expected to use knowledge gained from school science lessons to provide a possible scientific explanations for the observed increase in rats and rabbit populations. The activities required pupils to identify critical piece(s) of information necessary for the possible scientific explanation to the problem.

Unit 6 *Speed of Sound and Light*: Pupils were asked to discuss in groups their colleagues' explanations of a question and use their knowledge of how sound and light travel to generate a scientifically plausible explanation. The tasks designed required pupils to identify a critical piece of information for a scientifically plausible conclusion.

Unit 7 *How Sound Energy Travels*: Pupils were asked to discuss in a group statements made by their class mates regarding how sound energy travels. They were to use knowledge they gained from school science lessons to plan and design experiments to support their explanation. The tasks required pupils to design critical experiments and identify the critical factor for the result of the experiment to be more reliable.

The activities from each of the teaching units were designed specifically to develop the strategies or skills necessary for pupils to see the experiments as ways of asking questions in problem solving situations. This involved pupils working as a group to generate possible solutions to a problem, plan and design experiments to test what they perceived as a critical piece of information and make conclusions that are scientifically viable. To work on these units, the class was divided into small groups of 4 to 5 pupils. Each small group was requested to select one member to write down their answers on the answer sheet provided.

On completion of the unit exercises, each class was engaged in a discussion focused mainly on the authenticity of the approaches used by the different groups. Pupils were requested to remain in the same group throughout the sessions on teaching units in order to get acquainted with each others ways of presenting arguments and thinking things through.

Eloosis was now used as a teaching tool after the completion of the units. The game was played in the same manner as in the first part of the study. At the end of the game, pupils were engaged in discussions geared towards establishing the link between the game played and how scientists investigate solutions to natural phenomena.

Two evaluations (lasting 20 minutes) were developed to test further the extent to which Botswana school pupils (13-15 year olds) were able to identify critical pieces of information necessary to work out solutions to problems and plan and design critical experiments to test their line of thought.

Items for this evaluation required pupils to provide their personal information, their opinions on how they think they can learn science better, their general opinions about the units they worked on, their feelings about working in groups and to demonstrate the thinking skills they gain from science lessons (control group) and units (experimental group).

A sample of 21 pupils (10 boys and 11 girls) from three of the four schools used in the study were selected from each year group and interviewed in groups of three. The interview consisted of 23 questions in an unstructured form. The purposes of the interviews were to test the validity of the questionnaire and to gain richer insights.

The chi-square test was used as a 'goodness of fit' test to see if each experimental group differed on each question when compared to the control group. The control groups were also compared to look for developmental evidence. The distributions of pupils within each category were as follows:

**Table 2**
**Sample sizes**

| | Year 1 | Year 2 | Year 3 |
|---|---|---|---|
| Experimental | 94 | 156 | 92 |
| Control | 93 | 202 | 115 |

### Results of questions 7, 8, 9 and 10

Questions 7, 8, 9 and 10 were designed to test pupils' ability to apply successfully skills they learned from solving problems in school science lessons (in the case of control and experimental groups) and from working on units designed by the researcher (in the case of the experimental group). Specifically, these questions attempted to gain evidence about whether pupils could understand the place of the empirical in gaining evidence, how to devise appropriate experiments and how to identify critical pieces of information. The questions are reproduced as used and the pupil responses to these questions are now discussed.

(7) A local cattle farmer has 500 cattle. The cattle are grazed outside everyday for 9 hours and then spend 15 hours inside the kraal. The cattle farmer has been asked by a local vegetable farmer to supply 500 kg of kraal manure every week for a year. The vegetable farmer has agreed to collect the manure using her truck.

Before agreeing to supply kraal manure, LIST UP TO FOUR things that the cattle farmer should know.

1. ______________________
2. ______________________
3. ______________________
4. ______________________

Which **ONE** of the things you listed is MOST IMPORTANT in determining whether the cattle farmer will be able to supply enough manure? *(Write the number).*

From a list of up to four things that the pupils have named, only one of them was critically important for the cattle farmer to know before agreeing to supply manure every week for the whole year (do that number of cattle produce enough manure?). Pupils were to indicate this critical thing by writing down its number. Only this outcome is considered here.

**Table 3**
**Correct Responses to "MOST IMPORTANT thing"**

| | Sample | Group | % |
|---|---|---|---|
| Year 1 | 94 | Experimental | 6 |
| | 93 | Control | 4 |
| Year 2 | 156 | Experimental | 12 |
| | 202 | Control | 8 |
| Year 3 | 92 | Experimental | 13 |
| | 115 | Control | 16 |

There were no significant differences between the performances of the experimental and control groups at all years of study with the Botswana pupils. However, there seems to be clear evidence of a developmental effect. This is demonstrated by the gradual increase in the number of correct responses from year 1 to year 3 pupils in both control and experimental groups. Looking at the control groups, the developmental effect is confirmed by a chi-square value of 8.3 ($p < 0.05$).

(8) Tebogo has been studying global warming and wonders how scientists know what is actually the truth about global warming. Her friends suggest several ways to find the answers. These are listed in the shaded box.

A Read Scientific books
B Talk to experts like University professors
C Carry out experiments to test the idea of global warming
D Collect as much information as possible about global warming
E Assume global warming is true and act accordingly
F Use intelligent guesswork
G Look at information which has already been gathered through research
H Accept what majority of people believe is true about global warming

Arrange these suggested answers in order of their importance by placing the letters A, B, C...etc. in the boxes below. The letter which comes first is the <u>most</u> important and the letter which comes last is the least important for you.

Most important Least important

Pupils were to respond to the item by arranging the suggested answers in their order of importance, starting with the most important. In the opinions of a group of 'experts' (experienced teachers and lecturers), it was expected that pupils would rate C the most important followed by D, and finally G if the pupils had an appreciation of the place of the experimental. Thus, choices C, D and G were considered to have highest priority if pupils appreciated the importance of the empirical in drawing conclusions. The choices of positions of these three options on the eight point scale were considered. The proportions of pupils place C,D and G in the first three positions of the eight point scale were noted but the exact ordering was not taken into account.

**Table 4**

**Responses to question 8**

| | | Positions 1 to 3 | Positions 4 and 5 | Positions 6 to 8 | $\chi^2$ (df) | significance level | favoured |
|---|---|---|---|---|---|---|---|
| **Item 8C** | *Carry out experiments to test the idea of global warming* | | | | | | |
| year 1 | Experimental | 70 | 25 | 5 | 10(1) | 1% | experimental |
| | Control | 53 | 25 | 22 | | | |
| Year 2 | Experimental | 64 | 19 | 17 | 6.3 | 5% | experimental |
| | Control | 57 | 28 | 15 | | | |
| Year 3 | Experimental | 56 | 27 | 17 | 1.6(1) | n.s | - |
| | Control | 63 | 30 | 7 | | | |
| **Item 8D** | *Collect as much information as possible about global warming* | | | | | | |
| year 1 | Experimental | 60 | 31 | 10 | 1.9 | n.s | - |
| | Control | 52 | 35 | 13 | | | |
| Year 2 | Experimental | 61 | 26 | 13 | 2.1 | n.s | - |
| | Control | 63 | 28 | 9 | | | |
| Year 3 | Experimental | 74 | 21 | 5 | 1.6(1) | n.s | - |
| | Control | 67 | 28 | 5 | | | |
| **Item 8G** | *Look at information which has already been gathered through research* | | | | | | |
| year 1 | Experimental | 25 | 24 | 51 | 5 | n.s | - |
| | Control | 32 | 29 | 39 | | | |
| Year 2 | Experimental | 25 | 46 | 29 | 2.4 | n.s | - |
| | Control | 31 | 40 | 29 | | | |
| Year 3 | Experimental | 58 | 25 | 17 | 16.3 | 1% | experimental |
| | Control | 38 | 44 | 18 | | | |

It can be observed from table 6 that the differences in performances between the experimental group and the control group pupils are generally non-significant except in item 8C (year 1 and year 2) and item 8G (year 3). In all the three cases where the differences were significant, the experimental group scored 'higher' than the control group and it is possible that this could be attributed to the effect of the teaching units and Eloosis.

Overall, in looking at their views of the 'carrying out of experiments', it is clear that the three experimental groups do better but the control group catches up by year 3. It may be that their fascination with experiments is not a guarantee for understanding the purpose and function of experiments. However, those who worked on the units (experimental group) are more in favour of using experiments (8C) to question phenomena. This could be an indication that the units had an impact.

When looking at the control groups *only*, there are no significant signs of developmental changes in 8C or 8D but, in 8G, a chi-square value of 16.3 (df4) is obtained ($p<0.05$) showing that, by year 3, there have been changes.

(9) Here are some statements which are known to be true by experiment:

(a) The substance sodium fluoride contains the elements sodium and fluorine only
(b) A solution of sodium fluoride in pure water conducts electricity well
(c) The products obtained when electricity is passed through the sodium fluoride solution in
water are hydrogen and oxygen

Look at these statements, which of the following is true? *(Tick the box next to the true statement)*

(1) Sodium fluoride contains hydrogen and oxygen
(2) Water contains hydrogen and oxygen only
(3) Hydrogen and oxygen are everywhere
(4) Water contains hydrogen and oxygen

In ONE sentence, describe the experiment which should be carried out to be sure that your answer is correct. ____________

The first task required the pupils to select from the four statements listed one that they considered true. The second part asked the pupils to describe an experiment that would offer evidence to support their answer.

**Table 5**

**Responses to first part of question 9**

| | | correct | $\chi^2$ (df) | sig. level | more favoured |
|---|---|---|---|---|---|
| Year 1 | Experimental | 59 | 0.7(1) | n.s. | - |
| | Control | 65 | | | |
| Year 2 | Experimental | 56 | 0.2(1) | n.s. | - |
| | Control | 54 | | | |
| Year 3 | Experimental | 65 | 1.5(1) | n.s. | - |
| | Control | 74 | | | |

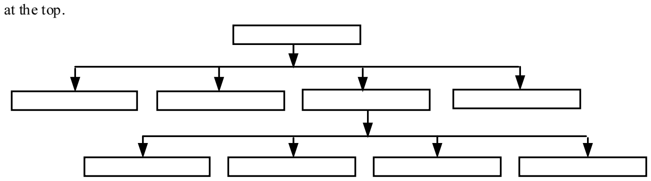
No significant differences between experimental and control groups were found but a chi-square value of 10.9 as a contingency test ($p<0.01$) was found when comparing the control groups. Again, year 3 performed significantly better than years 1 and 2, perhaps suggesting a developmental effect.

The number of pupils who responded correctly to the second part of question 9 was too small (<10% were correct in any group) for all groups for any statistical analysis to be carried out. Clearly, most of the pupils in all groups were unable to suggest a critical experiment.

(10) The table below gives information about a family, from grandmother to grandchildren. It is the year 2000.

| | | |
|---|---|---|
| <u>Grandmother</u><br>Still alive in the year 2 000 | <u>Aunt</u><br>10 years older than uncle 2 | <u>Uncle 1</u><br>4 years younger than aunt |
| <u>Mother</u><br>In 1960, she was the same age as grandmother in 1927 and 4 years younger than Uncle 1. | <u>Uncle 2</u><br>2 years younger than mother . | <u>Potso</u><br>In 1990, her age was one-fifth the age of her Aunt |
| <u>Bodo</u><br>In 1985, his age was half the age of Potso | <u>Pako</u><br>2 years younger than Bodo | <u>Vanessa</u><br>2 years younger than Pako |

Use the information given in the table to complete the family tree diagram below, with grandmother at the top.



What other piece of information would you need about Vanessa to work out the age of her grandmother in the year 2000? ____________

The first part required the pupils to complete the family tree diagram using the information provided in the table. The key thing was to place the 'mother' on the correct box. For the second part, the pupils neded to respond by either 'Vanessa's date of birth' or 'Vanessa's age'.

For the first part about one quarter of the pupils in each group completed the family tree correctly. There were no statistical differences between groups. In fact, the majority of the pupils were able to complete the family tree diagram but most ignored the critical position of 'mother' on the diagram.

**Table 6**
**Responses to second part of question 10**

| | | Correct answer | $\chi^2$ (df) | sig. level | more favoured |
|---|---|---|---|---|---|
| Year 1 | Experimental | 11 | 1.3 | n.s | - |
| | Control | 8 | | | |
| Year 2 | Experimental | 23 | 2.3 | n.s | - |
| | Control | 18 | | | |
| Year 3 | Experimental | 23 | 0.5 | n.s | - |
| | Control | 20 | | | |

Pupils performed badly on the second part. An explanation for this failure by the pupils could be attributed to the amount of information (noise) contained in the item and the fact that the pupils are culturally not familiar with the concept of family tree diagrams. There is some sign of improvement with age but only with the control groups (using chi square as a test of contingency) is this significant ($\chi^2$= 7.0 (df2), p<0.05).

When the responses of subgroups from Botswana formed according to gender were examined, more or less no significant differences were found. This is interesting in that, if some of the abilities being measured are developmental, then the developments are not gender related.

However, the evidence obtained from the pupils' responses to the test items clearly indicate that the ability to see an experiment as a way of asking questions during problem solving cannot be homogeneously accelerated through a single teaching approach. The fact that individual learners have unique ways of receiving and interpreting information presented to them is consistent with this observation.

**The interview results**

An attempt was made to obtain more information on pupils' conceptualisation of the place and nature of experimentation in scientific enquiry in Botswana. Pupils whom the schools considered high achievers in integrated science were selected by their science teachers. For the purpose of this project, three pupils per year of study from each school were used. It was felt that such pupils might be best placed to reveal their thinking.

The first group of the interview questions were designed to investigate further the pupils' interests in science as a subject (simply to get them talking). These are not discussed further here. Questions were then asked to determine whether pupils comprehended the purposes of experiments they carry out during their science lessons. In addition, pupils were asked to provide their opinions on why they are asked to work in groups when carrying out experiments.

The final part of the interview required pupils to express their perception of how the effects of experimental results help to shape their conceptual knowledge of every day events. The responses from the interview questions were recorded by carefully selecting common ideas in the students responses and recording them. Many of the responses are not relevant to the theme of this paper and are not discussed further here. Important remarks from pupils are italicized.

*What do you usually do during science lessons that interest you*?

All the pupils asked said spontaneously "carrying out experiments". However, when probed for more information, some pupils said they were also interested in watching video shows on nature conservation, family life, and the human body. The common reasons for having interest in these part of science revolved around the *relevance* of the knowledge gained to their *everyday experiences*. These responses are consistent with findings elsewhere (Reid and Skryabina, 2002)

*Tell me the things that you hate/love most about science lessons*?

Amongst the many responses given, the majority of the pupils regarded the writing of lengthy notes and the difficult language used to describe concepts as the things they hated about science lessons. However, as expected, all the pupils said they *loved working in groups* and *handling scientific apparatus*. Again, these confirm other findings (Reid and Yang, 2002; Reid and Skryabina, 2002)

*Do you do experiments during your science lessons*? *How often*?

While all said 'yes', a majority of the pupils, particularly year 2s and 3s, were quick to point out that the frequency with which they are engaged in experimental activities depended on the topic.

*Why do you think the teacher asks you to do experiments*?

They perceive science experiments as activities designed to enhance *better understanding of concepts*, to enable them to *experience science in action* and to have a chance to handle and manipulate science apparatus. A few pupils, however, were able to state that teachers asked them to carry out experiments in order to '*prove things true*'. These answers confirm that these pupils hold views which are very different from seeing experiments as ways of gaining evidence.

*Do you like doing these experiments*?

80% of the pupils thought that the experiments were necessary, but *failed to substantiate their positio*n. Some felt that some experiments they have done in science were not necessary, indicating that some of the experiments they carried out in science lessons either did not produce results or something went wrong and they had to abandon them.

*Why do you think your teacher always asks you to work in groups during experiments*?

The responses alluded to the notions of sharing ideas, helping each other to understand instructions and shortage of apparatus. When asked to explain the benefits of working in groups during experiments, there were no reasonable responses given.

When looking at their every-day lives, all felt that they could use knowledge gained from school experiments to solve problems encountered at home. Years 1 and 2 could not provide example of such problems but, some year 3 pupils mentioned the filtering of water containing undissolved impurities and subsequent boiling of the water to make it safe for drinking. All pupils interviewed considered education vital for increasing one's ability to think and develop better skills for doing things but three quarters failed to explain how knowledge gained from experimenting in school science could help them improve their lives. In fact, one third of the pupils felt that we should believe fully in experimental results because scientists who carried out those experiments are intelligent and everything they do is true!

**Summary of findings**

If indeed schools teach pupils to acquire the skill of experimenting and its place in scientific enquiry, the message is clearly not getting through to the pupils or the pupils are simply not ready cognitively. A few instances of the developmental effect suggest that as pupils have more exposure to science content and grow in maturity, significant signs of differences in the ability to see experiments as ways of questioning during scientific thinking increases.

The developmental aspects need further discussion. Information processing arose, in part, as an attempt to make some kind of sense of the remarkable observations made by Piaget (1967) in relation to cognitive development. Specifically, as the working memory grows in capacity with age (at about 1 chunk for every two years of age to the age of about 16), the learner gains greater cognitive capacity to handle many ideas at once. In addition, increasing knowledge and experience offers strategies for further chunking to occur enabling the working memory to handle increasingly complex ideas: information processing suggests that individuals can learn to group isolated units of information (chunking) in order to increase the amount of information to be recalled (eg Johnstone and El-Banna, 1989; Johnstone, 1991). However, this process does not happen automatically and certain frames of thoughts ought to have been developed which are dependent on the individual's experiences. It is a highly idiosyncratic process.

Therefore, the inability to conceptualise the place and nature of experimentation in scientific thinking by lower secondary school pupils could be an indication that their cognitive ability with regard to this concept is not yet fully developed or has not yet developed in some pupils. This may simply be lack of knowledge and experience as well as the inadequate capacity of working memory. It is also clear that the teaching units and Eloosis had had a limited impact on pupils. In some cases the effects were significant and in other instances the effects were insignificant. It would be interesting to see what the effects of a prolonged use of the units and Eloosis would yield.

The results from the first study are consistent with the view that the way of asking questions in scientific investigations is developmental although the limitations of the test instrument have already been noted. Subsequently, the analyses of later results reveal that the use of appropriate teaching seemed to generate very limited improvement in this skill. Although in a few cases there was significant differences between the experimental and control groups which was due, perhaps, to the effect of the units and Eloosis teaching, generally the difference in performance between year groups was not significant. The data strongly suggested that a developmental factor *might* be at work. Thus, cognitively, pupils were not yet ready to appreciate the abstract notions inherent in seeing the empirical as the way of gaining answers in scientific enquiry.

To investigate the effects of culture and the differences in educational approaches on the conceptualisation of the place and nature of experimentation in scientific thinking by early secondary school pupils, the assessment was applied to the Scottish pupils, of broadly similar age. 741 were involved of ages 12-14. While there were some differences, the general pattern of responses in most cases were remarkably similar. This suggest that the data reflect pupils' abilities in the skills being tested are not unduly affected by cultural and educational factors.

**The use of Eloosis in Scotland**

To explore the developmental ideas further, the game Eloosis was used with 120 pupils in years 1-4 of a Scottish school. The aim was to see whether there were any observable differences in the ways pupils responded to it. An experienced teacher followed precise questioning guidelines with each class while the responses were recorded. Often the responses were quantitative: for, example, in a question which asked, '*...did you try a card you thought might be accepted or might be rejected*', pupil views in each group were found by a show of hands.

Despite the difficult nature of the game (less than 10% thought it easy), pupils overwhelmingly indicated that they enjoyed playing the game (typically, over 90%) as was the case with Botswana pupils. However, further investigations revealed that pupils' enjoyment of the game did not necessarily mean they understood the processes involved in working out the teacher's rule. The results of various questions clearly demonstrated the uncertainty in pupils' thought processes.

When asked, '*Did you sometimes think you had the answer, then the next card made you changed your mind?*', around three quarters said '*yes*', suggesting reasonable honesty. However, when they were asked what they did when they thought they had the rule, in most groups around 50% said they tried to play a card which they thought would be *accepted*. Interestingly, the percentage of those who stated they tried to play a card which would be *rejected* to test the rule rose steadily by age group, from 23% in year 1 to 60% in year 4. This might suggest some kind of development by age of the idea of falsification. However, when asked which tactic was better, responses showed no pattern by age at all. They were then asked which tactic made them more certain and, again, responses were completely unrelated to age. Surprisingly over 80% of year 4 pupils considered *accepted* cards as the main source of evidence that they relied upon to work out the teacher's rule and almost completely claimed to have disregarded the pattern from rejected cards.

The responses provided by the pupils on the method they used to work out the teacher's rule clearly manifest a trial and error approach by all. The pupils could not spell out clearly the critical information that they had to hold onto to work out the rule. The pattern of thought observed with the Scotland group is similar to that observed with the Botswana group. To determine the pupils' perception regarding '*what message they gained from the game'* and '*how the message relate to the way scientists try to find answers to phenomena'*, more questions were answered.

Further questions, of a more general nature, were asked:

What do you think the game taught you?

How does the game relate to how science tries to find answers?

Why do we conduct experiments in science lessons?

What is science trying to teach us

Are some experiments better than other? What makes a good experiment?

Are answers from experiments always right?

How can you be certain of the answer from an experiment?

Generally, pupils vaguely related Eloosis to experimenting in scientific investigations. Through the use of some probing questions and clues provided by the experienced teacher, some answers were obtained. It became clear from the responses given by the pupils that some of their views were based on common knowledge which is not necessarily scientific. The majority of the pupils in all the year groups strongly felt that the process of scientific inquiry is logical and follows a set of sequential steps. However, their perception was consistent with the role of technicians who are required to follow a set of instructions to conduct an experiment.

It is not surprising, therefore, to see from the results that neither could the pupils state the purpose(s) of experiments correctly nor state attributes of a good experiment. Could this be a reflection of how the pupils are taught in schools or merely lack of knowledge. Encouragingly, the pupils were able to recognise that not all experiments provide the best answers. However, they could not explain scientifically how they could differentiate between good and bad types of experiments. Neither could they describe how they could verify an experimental result.

It is obvious that if some of the school science aims are to develop skills necessary for experimenting in scientific investigations, as stated in majority of school science curricula (i.e. plan and design experiments, decide on variables to manipulate during the experiment, make conclusions that are scientifically sound and so on), then, either the schools are using the wrong approaches (or not teaching it all) or simply the pupils are not ready cognitively. Perhaps the latter explanation is more plausible.

**Summary of purpose of the research**

The overall aim of this project is concerned with the ability of lower secondary level pupils to conceptualise the use of an experiment as a way of asking critical questions during investigations in their science lessons. This aim produced five questions which were explored in the experimental work described in this paper.

*(1) Do pupils at lower secondary level appreciate the inclusion of experiments in science learning?*

It seems clear that pupils have a very different perspective on the nature and purpose of experiments when compared to the place of the empirical in scientific inquiry. Even after specific teaching using the teaching units and the game Eloosis, pupils still do not seem to have a clear understanding. With Scottish pupil, the general outcomes seem to confirm that the teaching approaches used there appear not to have accelerated the development of the ability to see experiments as a way of questioning critically in scientific investigations.

The Nuffield Science syllabuses in England were based partly on Bruner's discovery learning approach which has strong connection with the scientific way of inquiry. Syllabuses had to be modified radically when it became clear that pupils could not cope with this approach. It is possible that pupils had not yet reached the developmental stage where this view of the place of the experimental was accessible. This is consistent with the findings here.

However, it is surprising to see the pupils showing strong appreciation for the inclusion of experiments as part of their science activities despite their lack of knowledge on the purpose of experiments. It became clear from the interviews that pupils were confusing experiments with practical work or situations where they follow a set of instructions to confirm answers to a teacher designed problem. It is very clear that pupil perceptions of the place of experiments is very different from the stated intentions of curriculum planners. Generally, all pupils at junior secondary level regard experiments as their main attractions to learning science at schools. This finding is consistent with the results from other research (eg. SKRYABINA, 2000; WOOLNOUGH, 1991).

*(2) Can these pupils identify a critical piece of information necessary for providing a credible solution to a problem?*

It appears that pupils are unable to fulfill this goal in the first Botswana survey. This result is not surprising given that the skills involved in identifying a critical piece of information and in scientific experimentation are highly abstract and that these pupils are in the transitional stage of formal operations as described by Piaget (1967). However, it must be noted that this conclusion was based on test/questionnaire whose validity was open to question. It represented an attempt to gain information about a highly complex matrix of thought processes but the complexity of this raises doubts about validity. Nonetheless, the evidence from the larger survey conducted in Botswana and the parallel Scottish study support the general finding. The data also suggest that it is not easy to develop such skills by specifically targetted teaching.

*(3) Do lower secondary level pupils have the ability to conceptualise or see experiments as ways of asking critical questions in scientific investigations?*

Pupil see experiments as illustrative, as fun, as ways of making the taught course 'real'. There is no evidence to suggest that their perceptions of experiments are similar to those often specified in curriculum guidelines.

*(4) Can the development of the experimenting skill in those pupils at lower secondary level who have not yet developed it be accelerated through appropriate teaching?*

Specifically targetted materials were used in Botswana and there is some evidence of changes in pupil perceptions. However, there is little evidence that such materials can bring about pupil appreciation of the nature and place of the experiment in scientific enquiry. The Scottish data seem to support this general conclusion.

*(5) Can lower secondary pupils from completely different teaching and cultural backgrounds demonstrate similar performances in terms of seeing the experiment as a way of asking critical questions in scientific investigations?*

There were differences between the Botswana outcomes and the Scottish outcomes. However, it is never easy to be sure what causes what in that the two pupil populations live in very different cultures, face different curricula, are both taught in English (but this is a second language in Botswana), use textbooks differently and face a different assessment system. There are, inevitably numerous other differences. The general impression left is how similar the pupil responses are, despite these many differences. This would suggest that the pattern of outcomes is a reflection of the nature of the test material and the psychological stage of development of the pupils at these ages.

## CONCLUSIONS

It has to be admitted that this paper describes experiments seeking to probe a highly intractable area of understanding. Identifying a critical piece of information necessary for use in exploring possible solutions to problem in scientific investigations appears to be highly complex and, therefore, fairly inaccessible with pupils at lower secondary level. The great problem lies in gaining the evidence of how the pupils are thinking in this area. Criticisms can, of course, be leveled against any test material; validity is difficult to assess in this case. Nonetheless, with populations in two countries coupled with the interviews conducted, it is clear that pupils *do not see the place of experimentation in science in a way remotely related to that advocated by curriculum planners*.

The difficulty is knowing whether this is a developmental issue in that pupils are not yet cognitively equipped to handle such abstract notions although the evidence is consistent with this. Information processing ideas may offer a way forward in the exploration of this. Perhaps, teachers do not possess the knowledge and the skills of experimenting to effectively pass them on to the pupils or, almost certainly, they do not have the time to attempt it.

In an tantalizing but unstructured extension, the experienced teacher tried out Eloosis with pupils aged 16+ and 17+ pupils. The reported outcomes were very different. After playing the game, both groups went into a deep and prolonged discussion with the teacher and seemed to grasp completely the purpose of the game, the nature of experimentation, and the idea of a critical experiment (the playing of a specific card to test a hypothesis, the rejected card able to undermine an hypothesis, the accepted card able to support it). This is an experiment waiting to be conducted in a more formal way to see if, indeed, such understandings can only be reached at certain stages of cognitive development. The evidence so far has raised a fundamental question, answers to which may influence the planning of school curricula quite considerably.

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