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ABSTRACT

A study investigated the extent to which students' inquiry skills can be facilitated through the use of a computerized science database (Birds of the Antarctica) and specially designed curriculum materials. Much attention was given in the program to developing both students' inquiry skills and their subject-matter knowledge. Grade 11 and 12 students' knowledge and skills development were interpreted as they interacted with the computerized database and the curriculum materials. The constraints to the development of inquiry skills and construction of understanding were identified. The theoretical framework of the study was based on a constructivist epistemology. An interpretive research methodology was employed to interpret students' and teachers' engagement in sense making and negotiating meaning. The results of a test of inquiry skills provided supportive data that helped to answer the main research question of how students develop inquiry skills. (22 references) (Author/KR)

DEVELOPMENT OF STUDENT INQUIRY SKILLS: A CONSRUCTIVIST APPROACH IN A COMPUTERISED CLASSROOM ENVIRONMENT

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Abstract

This paper discusses a study which involved investigating the extent to which students' inquiry skills can be facilitated through the use of a computerised science database (*Birds of the Antarctica*) and specially designed curriculum materials. Much attention was given in the program to developing both students' inquiry skills and their subject-matter knowledge. Grade 11 and 12 students' knowledge and skills development were interpreted as they interacted with the computerised database and the curriculum materials. The constraints to the development of inquiry skills and construction of understanding were identified.

The theoretical framework of the study is based on a constructivist epistemology. An interpretive research methodology was employed to interpret students' and teachers' engagement in sense making and negotiating meaning. The results of a test of inquiry skills provided supportive data which helped to answer the main research question of how students develop inquiry skills.

Teacher epistemology shaped the learning processes in the classes and influenced the nature of the higher-level thinking skills and the extent of their development. An increase in students' levels of thinking and the use of higher-level inquiry skills occurred mainly in classes where teacher initiated discussions and negotiations of meaning became an integral part of the learning processes. In these classes, students were able to generate higher-level questions and design complex investigations while interacting with the database. These classes also were characterised by significant gains in achievement as measured by the inquiry skills tests.

BACKGROUND

INQUIRY-BASED SCIENCE TEACHING

During the past quarter of a century, teaching science as inquiry (Schwab, 1963) has gained considerable prominence in science education. This approach arose from a fundamental need in science education to teach science as an active process involving inquiry and knowledge, rather than relying on exposition of content alone. Scientific inquiry has been defined in operational terms as involving a set of specific processes or skills, including planning experiments, collecting information, organising and interpreting information and drawing conclusions (Fuhrman, Lunetta, Novick & Tamir, 1978), which are used by scientists in their work.

A significant departure from the notion of inquiry suggested by Schwab (1963) and Fuhrman et al. (1978) was expressed by Kuslan and Stone (1969) who emphasised that inquiry learning is "why" centred, and not a prescribed set of skills for solving scientific investigations. They referred to effective science teaching which integrates the notions of science as information and science as the search for understanding. In their approach to inquiry learning, the answers are not known in advance, and questions such as "How do you know...?" are characteristic of the inquiry style.

In spite of its promise, inquiry-based science teaching had been largely disappointing in the past. Classroom observations reveal plenty of examples of the absence of inquiry teaching/learning or opportunities for higher-level learning (i.e. understanding and inquiry skills). Weiss (1987) and Tobin & Gallagher (1987) report that most science curricula emphasise learning of facts and place little emphasis on higher-level cognitive learning. Many programes that claim to be inquiry-based show little evidence of inquiry on the part of students (National Research Council, 1989; Stake and Easley, 1987; Tobin and Gallagher, 1987). Instead they emphasise whole class activities led by the teacher, and the use of textbooks and worksheets which stress the learning of facts and the application of algorithms. Moreover, evaluations of inquiry-based programs usually have revealed a failure to promote higher-level cognitive outcomes. For example, an evaluation of Australia's first national inquiry-based curriculum, the Australian Science Education Project (ASEP), revealed that ASEP students were no better than students following traditional curricula in terms of performance on a range of inquiry skills (Fraser, 1979).

CONSTRUCTIVIST TEACHING APPROACHES

One likely explanation of why reforms in science education might not have been so successful in the past is that the central place of teachers and students in implementing change has been ignored (Tobin, 1990). In particular the failure of inquiry curricula could be linked to the way teachers have retained a "transmission" epistemology while inquiry based teaching requires a shift to 'constructivism'.

The constructivist approach focuses on learners constructing their own understanding, and on the social interactions taking place in the classroom. In a personal sense, the learner is actively engaged in constructing meaning by bringing his or her prior knowledge and development to bear on new situations (Driver & Oldham, 1986; Driver, 1990). In the social sense, construction of meaning takes place when students negotiate their understanding by engaging in class discussion, exchanging ideas (Prawat, 1989) or interacting with computer software in order to explore and develop further ideas (Oliver & Okey, 1986; Nachmias & Linn, 1987; River & Vockell, 1987).

COMPUTERISED LEARNING ENVIRONMENTS

Computerised classroom learning environments have the potential to overcome the management difficulties normally associated with inquiry-based learning and constructivist teaching, and therefore to promote the goal of higher-level cognitive learning. In the present study, students engaged in experiences which enabled them to develop higher-level thinking skills, be creative, and construct their understanding based on a computer program. The students engaged in making sense and constructing understanding by negotiating their own meaning with the teacher and the other members of the class. The information transmitted by the computer served as a basis for students to "construct the computer" (Papert,1988), that is, to reflect, make sense and generate more questions.

Today there is an increased emphasis on teaching and learning for understanding or, as defined by the Report of the Holmes Group (Young et al, 1990), 'learning for a life-time'. In the past, however, a majority of students characterised their experiences of computers in schools as giving them a strong negative attitude towards using a computer. Students recall experiences where they were involved in drill and practice exercises, where they keyed in computer programs from books or played what, in their eyes, were trivial computer games (Bigum, 1987). In contrast, the computerised learning environment in this study combined an inquiry-based curriculum with a constructivist approach to learning and emphasised learning for understanding.

PURPOSE

The purpose of the study was to investigate the extent to which students' inquiry skills can be facilitated by the use of a computerised database and specially designed curriculum materials. The focus of the research involved students' development of inquiry skills as they engaged in scientific investigation through the use of the database. It is important to study higher-level learning (i.e. understanding and development of inquiry skills) both as a process and an outcome:

1. Higher-level learning as a process - An interpretive, observational study was conducted in order to gain an in-depth understanding of the learning-teaching process.

2. Higher-level learning as an outcome - Tests were designed to assess students' development of science understanding and the following three levels of inquiry skills:

   - Interpretive skills such as interpretation of graphs and tables, and comparison of results from different investigations;
   - Analytical inquiry skills such as drawing conclusions, and explaining relationships between variables;
   - Applied (highest-level) inquiry skills such as generating a question and designing appropriate investigations to find answer to each question or to challenge each hypothesis.

METHODOLOGY/ PROCEDURES

The research study, which took place in four schools in the metropolitan area of Perth, involved 122 students in seven Applied Computing classes, six at the Grade 11 level and one at the Grade 12 level. Each of these students responded to the *Inquiry Skills Test*, designed especially for the study, as both a pretest and a posttest. The Inquiry Skills Test was designed to assess students' inquiry skills using the scales of Interpreting, Analysing and Application (Zohar & Tamir,1986).

Two classes that were randomly selected for the interpretive study approach exhibited an interesting pattern of teaching and learning. Both Applied Computing classes, had experienced interaction with computers before and had similar schooling and socio - economic backgrounds. The Grade 11 Computing teacher had taught at the primary school and upgraded his qualifications by completing a Graduate Diploma in Computing. The teacher believes that he should teach the curriculum and transmit the knowledge to the students. By doing so, he ensures that "they get the material, otherwise they cannot learn"(teacher interview June 1990).

The Grade 12 teacher also had a Graduate Diploma in Computing. He believes that the students are capable of constructing their own understanding, and he and the other members of the class should help in the process. With these two different teaching perspectives, we will examine the learning processes in the two classes.

In the program, which took approximately 25 hours to complete, students were involved in individual interactions with the computerised database and the specially designed curriculum materials, which consisted of a student booklet that guides students in using the database and retrieving information. The main purpose of the student booklet was to encourage the learner to generate questions and design investigations by using the different functions of the database. In addition, students and teachers engaged in class discussions to enable students to negotiate their understandings arising from using the program and their prior knowledge, and to verbalize their own ideas.

In order to investigate how students developed inquiry skills, the study employed an interpretive research methodology (Erickson, 1986) using the following data sources:

- field notes of classroom observations;
- audiotape recordings of classroom discussions;
- case studies of individual students' construction of inquiry skills based on audiotape recordings of students 'thinking aloud' as they interacted with computers and curriculum materials (Ericsson & Simon, 1984);
- intensive semi-structured interviews with students and teachers; and
- student entries in a student booklet designed for the study.

By means of triangulation of these data, the study sought some understanding of the learning processes involved in inquiry learning using a database, rather than a basis for prediction and control over the learning situation (Cziko,1989). The focus on the learning processes was guided by a 'social constructivist' approach to learning (Tobin, 1990). This approach emphasizes students' and teachers' engagement in class discussions in order to construct meaning and negotiate understanding.

The results from the Inquiry Skills Test were combined with the qualitative information in order to enable the construction of high-level inferences about factor which affect the development of inquiry skills.

FINDINGS

EARLY CONSTRAINTS TO HIGHER LEVEL THINKING

Database Language

From the start of the first lesson, most Grade 12 students interacted with the database and did not hesitate to try the different functions in order to retrieve information. Some demonstrated a good understanding of how to work with the database, as they followed the curriculum material (students' booklet) very closely and at their own pace, while the teacher, at this stage, was observing students interacting with the computers. While experiencing the

Help Screen (see Figure 1) and working with the first sets of Tests (investigations), students seemed to understand the framework and structure of the database. In particular, they developed their abilities to translate questions into the appropriate codes and, therefore, were able to use the language of the database. The Help Screen provided students with explanations of how to use the database language and the different functions of the database. In that first session all students experienced some of the different functions of the database, such as writing a test and retrieving information.

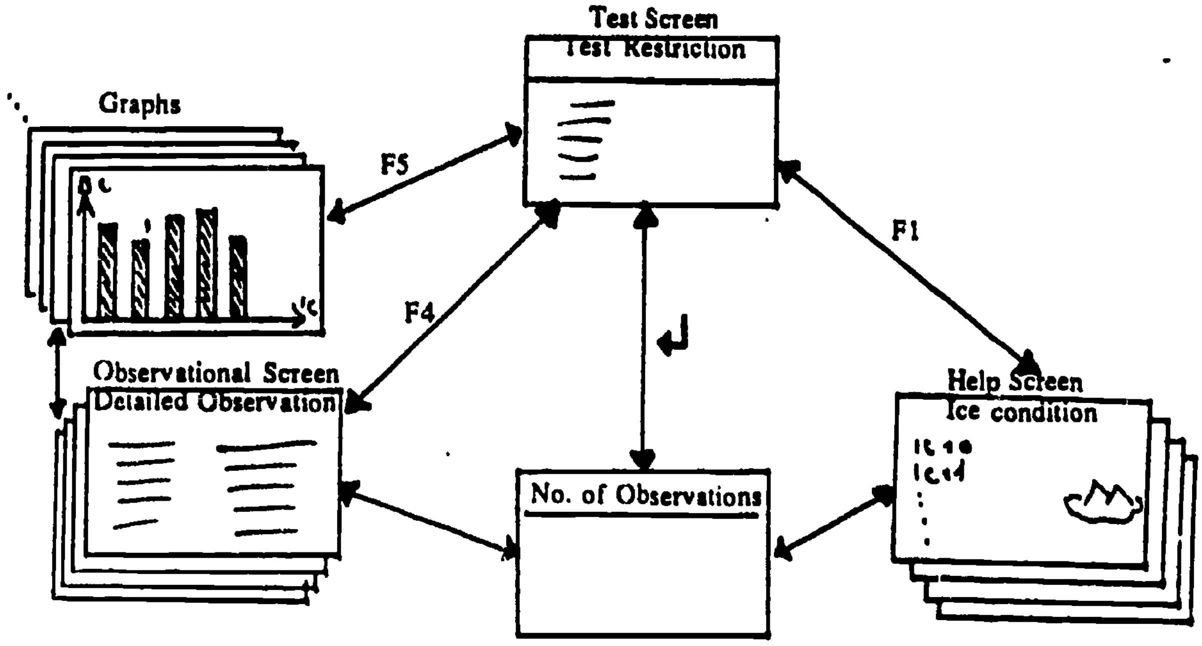

Figure 1. The structure of the database

The first obstacle that the students had to overcome was using the codes of the database in order to conduct a Test. The use of the language of the database required students to use certain codes. For example, when students were asked "How many observations were made when the sea was covered with ice?", they had to use the Help Screen to find the codes for "ice" (ic) and for the description "covered with ice" which corresponded with the value of 5. Then they were able to conduct the test using the coded statement "ic = 5".

Visual Understanding

Only after students had visualized the database could they easily leave the Main Screen (see Figure 1) and use the other options required to obtain the information. In an interview with a Grade 12 student the researcher asked how he solved a particular problem.

Anthony: *I pictured where the Help Screen is, and how to get to it and only then I was able to work effectively with the data.*

This visual understanding of the database increased the interaction between student and computer. Students easily shifted from Test Screen (see figure 1) to Help Screen, and back to Test Screen and Observational Screen. Most of the Grade 12 students seemed to prefer to use the Help Screen rather than the Appendix in the booklet and expressed enjoyment about their ability to control the data while using the Help Screen. These basic manipulations of the database, and use of different extensions of the database, were reinforced by the teacher in Grade 12 who prompted student interactions with the database by posing questions.

In the early stages of the program, most of the Grade 11 students found it difficult to visualize the structure of the database. They perceived the software as an abstract concept and could not move from one screen to another because of their inability to conceptualize the organisation of the database. The movement from one screen to another required a global understanding of the structure of the database which they could not acquire and, therefore, it took them a longer time to develop the practical skills which were elementary to the higher ability students.

To help with the visualization, the teacher of the Grade 11 class referred the students to a 'card catalogue' which he borrowed from the school library. He used a physical visual analogy to demonstrate the structure of the database to the students. In an interview the teacher explained:

> *I like to get students to think about a card file system where they can see concrete cards with all the information written on it. It is only when you approach these students in physical terms that they have a good chance of understanding and applying concrete ideas to the software which is quite abstract* (teacher interview 1 June 1990).

Subsequent to this teacher demonstration, many of the Grade 11 students constructed their understanding of the database and were able to overcome some of the practical skill problems which they were experiencing. However, one of the reasons which prevented students from manipulating the database was that the class was required to progress together in a 'lock-step' approach: students followed the teacher without having enough opportunity to experience the database by themselves. So, some of the Grade 11 students could not construct an individual understanding of the structure of the database. Visual understanding of the structure of the database would appear to be a prerequisite which enables students in Grade 11 and Grade 12 to manipulate the database and acquire practical skills.

Summary

During the initial stages of the study some of the Grade 11 students experienced difficulties in using the database language and in visualizing the database. Most of them overcame these constraints by individually interacting with the teacher, and spending more time interacting with the program in order to master the practical skills.

In a later stage of the study the students that did not overcome the constraints also did not develop the highest level of inquiry skills and were able to deal only with interpretation type of questions. The group of students that did not experience any constraints in using the database language, or visualizing or manipulating the database, were successfully engaging in the higher level of inquiry skills.

HIGHER LEVEL-LEARNING AS AN OUTCOME

Changes in Inquiry skills among the Total Sample

Use of the Inquiry Skills Test as a pretest and posttest showed a statistically significant increase in the mean score for the total sample of 122 students. In order to interpret these results, the pretest and posttest results for the total test and the subscales was plotted (see Figure 2). The graph enables a visual comparison of the relative performance of students for the total test and the three subscales. It also indicates the relative changes from pretest to posttest for the whole sample of 122 students. The mean scores in Figure 2 were calculated in percentages as the number of items for each scales varied. The statistical significance of pretest-posttest changes was investigated using t tests for dependent samples; the results are shown in Figure 2.

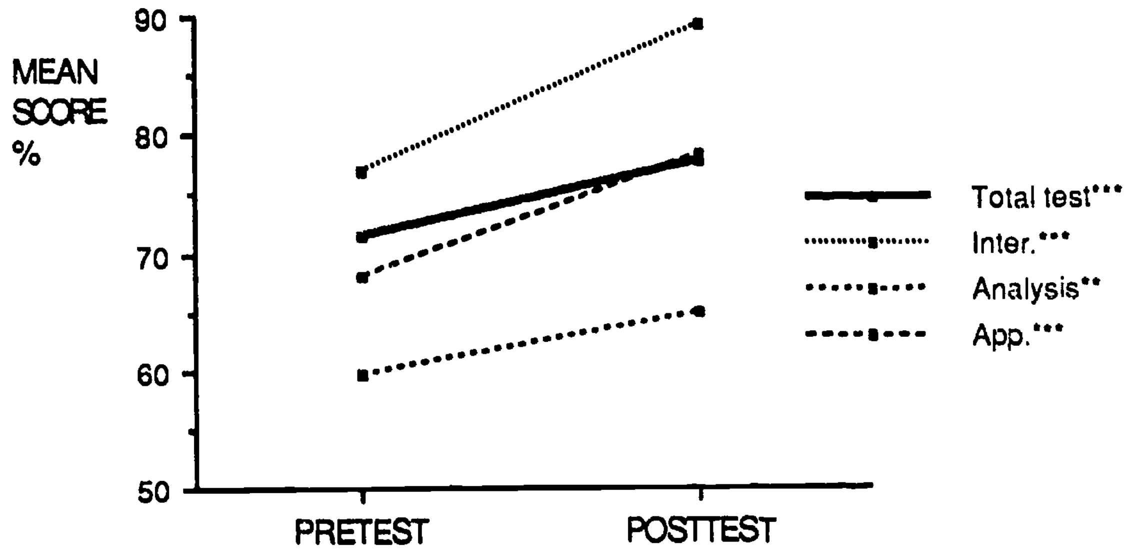

Figure 2. Mean score on the Inquiry Skills Test and the subscales for the whole sample (n=122)
*p<0.05 **p<0.01 ***p<0.001 (two-tail test)

Students' abilities to solve inquiry skills problems increased significantly on each of the three subscales, as well as on the test as a whole. The differences in the levels of significance indicate that students' interactions with the program were associated with greater effects on the Interpretation scale (approximately 0.87 standard deviation) and Application scale (approximately 0.5 standard deviation), and with a smaller effect on the Analysis scale (approximately 0.25 standard deviation). These results referred to the whole sample.

Inquiry Skills Performance for Individual Classes

A further analysis was made of the mean scores of the two classes selected for the in-depth study; this will be discussed in the later section on higher-level learning as a process. Figure 3 displays students' inquiry skills mean score results on the pretest and posttest, for the total test and three subscales.

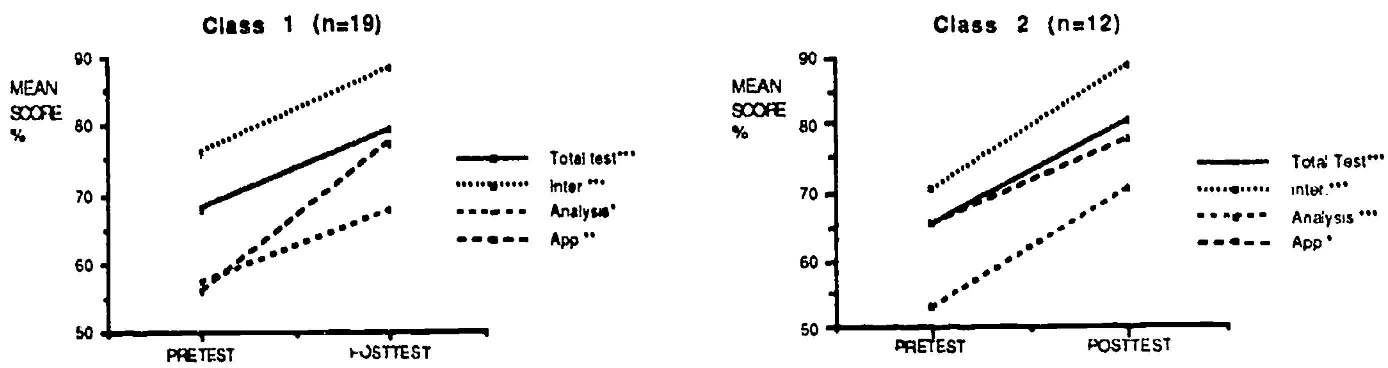

Figure 3. Students' mean score results in selected classes.
*p<0.05 **p<0.01 ***p<0.001 (two-tail test)

Students in both classes improved their inquiry skills abilities significantly. The mean scores for the total Inquiry Skills Test was significantly higher at the end of the program than at the commencement of the program. Students' abilities to solve inquiry skills problems also increased on each of the three subscales.

Generally Figure 3 indicates that at the beginning of the program, students in classes 1 and 2 were more able to solve Interpretation type of problems, less able to deal with Application type of problems (with a minor exception in class 1), and least able to deal with Analysis type of problems. This pattern of students' performance was repeated at the end of the program. Students in class 1 demonstrated a particularly larger gain on the application type of problems.

Summary

The Inquiry Skills Test was designed for the purposes of the present study and based on the ideas of Schwab (1963), and Zohar & Tamir (1986). The results of the Inquiry Skills Test reveal a global picture of the increase of students' performance in three areas of investigation, using the computerised database and specially designed curriculum materials. This section discussed the significant test results of Grade 11 and 12, the next section will discuss the different nature of inquiry skills developed in the two classes.

HIGHER-LEVEL LEARNING AS A PROCESS

Development of Interpretive Inquiry Skills - Design and Interpretation of Graphs

After the students manipulated the different functions of the database, they were able to practise their interpretive inquiry skills and, as the study progressed, they were able to discuss the different interpretation and meaning that they gave to the graphs which they constructed.

To a question on page 42 of the students' booklet "Which species were observed when the ice condition was 4 and more (i.e. covered with ice)?" , different students in grade 11 gave different interpretation and designed their tests accordingly. Neil, a student in grade 11, used a histogram and in Test Restriction (see Figure 1) put the relevant data about the ice (field notes 11 September 1990). The histogram displayed only the conditions that the student specified in the Test Restriction (i.e. species that were seen in ice condition 4 and more).

To the teacher prompting "Did anyone else come across any other ways of going about the same problem?", another student responded by giving his interpretation. He used a bar chart with the variables 'ice' and 'species'. In this example, the bar chart displayed all the bird species in all ice conditions and the students would have to extract the answer from the graph. This is a simpler design of the investigation, but it required better interpretation skills from the student. The teacher presented the two ways of conducting the inquiry using the computer. He compared the species that appeared on the screen in the two presentations. When the different Tests showed different results, the teacher was quite confused. He did not try to resolve the problem with the students, but referred to the researcher (who observed the classroom):

Teacher: *We got two different sorts of answers for that, quite frankly it says...why is this so?* (observation 11 September 1990).

The conflict in that situation was resolved by the researcher and not through negotiation between students and teacher.

The same investigation revealed a different scenario in grade 12. The discussions went further in order to resolve the conflict. The students were able to negotiate the meaning of some ambiguous questions with the teacher until they reached a consensus. This pattern of behavior falls within the framework of constructivism: teachers and students engaged in inquiry based sense making.

The grade 12 teacher raised the question about the difference between the two ways of presentation (i.e. histogram vs bar chart). Students were engaged in teacher-prompted discussion about the differences between the two methods. After negotiation students came up with the idea that the bar chart required more interpretation, which made its less effective.

Students soon realized which inquiry mode was the most effective for their needs. These different interpretations of the same question resulted in different designs of an investigation, one of which was more effective but required better understanding from the students. This phenomenon of different designs for the same question encouraged students to give explanations for their results, increased discussions and negotiation amongst students and teacher, and reinforced the development of interpretive inquiry skills.

As a result of developing interpretive inquiry skills, students were engaged in higher-level inquiry skills by drawing conclusions and explaining relationships between variables, and did not focus on the lower level on interpretation.

Development of Analytic Inquiry Skills - Constructing Hypotheses and Testing for Viability

In the early stages of dealing with the curriculum materials and the software, the Grade 11 students were asked to find different birds' behavior from the data and, then, to infer with reasons why most of the birds that were observed by the scientists were sitting on the ice. Some of the students suggested that the birds might be Penguins. One Grade 11 student used his prior knowledge in the following way:

> *Penguins like to sit on ice, so it must be a Penguin.*

He didn't go beyond guessing, and did not support his hypothesis by running another 'test' or checking the data. As the teacher mentioned:

> *The student didn't try to back his statement with any logical argument.*
> (teacher interview 1 June 1990).

Even when students did give reasons or explanations for behavior or phenomena, they usually did not go beyond the level of guessing, and did not support their argument with supportive evidence from the database. The fact that some of the students were not fully manipulating the database prevented them from individually exploring and designing more information retrieval. The other explanations that the teacher gave were:

> *I haven't found any of the students in either Grade 11 class who have the ability after they made a statement to back that statement with any form of logical argument or logical problem solving procedure or testing their statements... In the answer they said: "They are Penguins... so why bother?" They are not interested in the process.* (teacher interview 8 June 1990).

From this incident, it is clear that most of the Grade 11 students stayed at the "guessing" level and did not attempt to support their hypotheses by conducting more investigations and extending their use of the database. At this stage of the study, students' explanations and use of general knowledge to support their explanation were very limited.

During the program, this 'phenomenon' started to change, and slowly students became aware of the need to give explanation and support their hypotheses. Gen, a grade 11 student, wanted to find the relationship between the wind condition and the type of birds at the area of the research. She found that the Capped Albatross is the most common bird in violent storm condition. When the teacher asked:

> *Why do you think the White Capped Albatross may be seen in violent storms more than the other birds?*

the student replied:

> *Because the Albatross is one of the larger birds of Antarctica so they probably can withstand higher wind speed.*

In response to the request by the teacher she further designed investigation to support this hypothesis (field notes 14 September 1990).

This analytical inquiry skills was only partially achieved in Grade 11 as the discussion, interaction and making sense of the database in which students and teachers were involved, were limited in scope. The teacher let the children experience and explore the database, but most of the time led them to the conclusion and 'spoon-fed' them. The interactions and discussions in this class were not intensive and powerful to the extent the researcher would expect from the constructivist epistemology perspective.

In grade 12, where students already had gained the practical skills for dealing with the database, there was more discussion overall, and the discussion about the number of observations for certain birds' behaviour gained more momentum. Students used their general knowledge to interpret that birds sitting on ice are Penguins, but they were not satisfied with their hypothesis. They tried to give support to their initial hypothesis by designing a new investigation to find more information about the birds which exhibit the behaviour "sitting on ice". Firstly, they identified the 'bird species' and found that it was a Penguin, and not another species, by running another investigation through the database.

In another incident, the class discussion focused on the issue of whether it is always necessary to support or disprove a hypothesis by running more investigations on the database. To answer the question: What is your hypothesis about the preferred living conditions of (a) Emperor Penguin and (b) Wandering Albatross (student booklet p. 22), the class was divided in their ideas. One student answered the question by simply stating his hypothesis, whereas another student (Carl) replied:

Carl: *How can you say that? Did you check for other weather conditions?*
Anthony: *I just did what the question required, not more.*
Tom: *You have to do more Tests to find the answer.*

(field notes 18 June 1990)

Clearly in this case, the grade 12 class was divided into two groups. The group that did only the first step of formulating a hypothesis according to previous information (and this is one step above the initial step of guessing discussed above). They argued that they should stick closely to the booklet and the instructions. It seems that they couldn't see the need to further support their hypotheses. Most of these students obtained low or average scores on the Test of Inquiry Skills.

The other group reached a higher level of understanding of a scientific investigation. After making a hypothesis, they automatically engaged in designing more and different investigations to support their hypothesis. This group argued that:"You can't hypothesize without running a test and finding justification from the database " (field notes 18 June 1990). This group consisted of students who obtained high or average scores on the Inquiry Skills Test.

In an interview with Andrew, a Year 12 student, the researcher asked the student about the importance of constructing hypotheses as part of scientific investigation. The student replied:

> *You have to actually have a hypothesis... You have to have a theory about what the answers are going to be before you actually get them. And if they*

differ from the answers in your theory you have to work out why they differ, why you didn't pick it up in the first place?

(student interview 27 September 1990)

In th. same interview the student continued:

You know, as it (the program) progressed, I found myself analysing the information more, because I sort of got in tune with the question why would it ask that if, you know, not for any other reason that it wanted me to think it and get my views, not just what I got out of the database.

This interview serves as an example of a student making better sense of the database, a cognitive activity associated with the development of higher-level thinking skills.

As the study progressed, students in grades 11 and 12 were able to construct hypotheses to explain the data that were recorded by scientists. Some of the students developed higher-level skills by designing further data retrieval to support their hypotheses.

Development of Applied Inquiry Skills - Constructing Questions Through Creative Thinking

When the students were asked to generate new questions and design investigations accordingly, most grade 11 students limited themselves to the examples that were given to them in the student booklet, and did not proceed beyond the nar-ow level of this set of examples. Their understanding of the opportunities existing in the database was limited to what is "on the screen" and they did not demonstrate creative thinking to use the database "to its limit".

Towards the end of the program some students of the Grade 11 demonstrated an increase in the variety of questions that were asked and also increased in their creative thinking. For example at the beginning of the program (15 June 1990) Alan asked a very informative question such as: "What was the average sea temperature over the test?"

In a later date in the program (10 September 1990) the questions were less narrow in their scope. For example the question: "Did the birds count diminish over time?", required a careful design of the investigation. When the student was asked to reflect on his ability to ask questions, he responded:

At the beginning of the program I have picked up more ideas on what questions to ask by looking at the questions in the book,....I think the questions that I ask now will be deeper than the (previous) ones and have more meaning than the ones I asked before.

(interview with Alan 17 September 1990).

This student clearly demonstrated his development of higher-level thinking by being able to reflect on his ability to generate questions in the different stages of the study.

Even students who had problems in achieving practical skills at the beginning of the program demonstrated a development in their applied inquiry skills, meaning their ability to generate questions. Gen a grade 11 student provided an example of this behavior;

Gen : *I just wanted to see if any birds were seen sitting on the ice. I have got higher latitude like up around the 60° latitude to see if there was actually any ice out there and yes there was.*

(audiotape 14 September 1990).

Her question was a variation of a question asked in the booklet. Nevertheless she demonstrated a full understanding of the investigation which she wanted to conduct.

On the other hand, a small group of students, most of whom were in grade 12, came up with interesting questions and exhibited creative thinking. These students developed the practical skills and managed to manipulate the database without any problems. The questions were not confined to the content of the database, but extended to other related areas which the students inferred from the database.

For example, one of the students formulated the question: "Which bird is the most tame of all the 26 species?" This student designed a few investigations to answer his question. He ran the tests for all 'bird species' which demonstrate the behavior of 'sitting on the ship' or 'in the hand', or 'accompanying ship', or 'following its wake'. Based on the data that he received, the student wrote some assertions about that species being the most tame (field notes 15 June 1990).

When the teacher asked:"What new information about the environment have you acquired so far?, a student replied by describing an investigation that he designed to find the migration period of some of the species:

> *I tried to work out when migration periods for certain birds were. I chose several days during the time of the voyage and found out when different birds are at their maximum number*
>
> (field notes 8 June 90).

The student exhibited creative thinking from his area of interest and designed the investigation accordingly.

In a later stage of the program (15.8.90), in grade 12 when the teacher asked the students to introduce few of the questions they generated, there were a wide range of questions asked by different students:

> *How does bird behavior vary with air temperature? In what sea conditions was the Snow Petrol seen?, Which species were observed in the hottest temperatures and which in the lowest ones?*

One of the students demonstrated very creative questions and highly applied inquiry skills.

> *I was just exploring, finding out about the living conditions of the Antarctic South Polar and finding and watching how it interacted with other bird species and drawing conclusions from that.*

On the basis of his finding this student further explored about this bird using the library and presented the information to the students in the class. The student was able to reflect on the learning process that he had been through :

> *It (the program) wants more thought about what questions you asked as opposed to you just thinking of a question and typing it in....In worksheet 1 the questions types were: 'how often did the birds' .....Later it was the one about the Antarctic South Polar which was basically exploring the living conditions, and checking the data in the and describing how it interacts with other birds*
>
> (see example above, interview with Andrew 17 August 1990).

At another interview this student expressed the idea that:

the database didn't give me more information, it was just that I was analysing it differently than I was in the first question....My questions get more complicated as they go along because I know that if I pull my own conclusions from it that I can get more out of the database in general.
(interview 27 September 1990)

From the observations made, students were able to generate questions and develop creative thinking in their investigations only when they could easily manipulate the database. Then they were able to generate questions and, as one of the students expressed it:

Andrew: *I'm being more analytical in my thoughts than I generally do, I'm thinking more.* (interview 15 August 1990)

The teachers' responses to the student ability to generate questions represent their belief about teaching and learning. The grade 11 teacher commented:

I noticed they (few low ability students) asked very simple questions and on the other end you had someone like Alan who asked complex questions and extracted real complex answers out of it as well.

The teacher was surprised to realize that:

the majority of them were able to extract the questions from the database quite efficiently towards the end of it (the program), that's for sure.
(interview with Peter 28 September 1990).

This teacher was sceptical about students' ability to handle the database, and therfore questioned their ability to generate questions. Only a few students in this class were able to engage in personal and social construction of knowledge and develop higher-level inquiry skills, partly because of the teacher's 'transmission' approach to teaching.

By contrast the grade 12 teacher expressed satisfaction with students' abilities to generate questions:

The students were not just questioning the database, they had to start thinking about what question they are going to ask....they would have to achieved this sort of higher-level questioning we're talking about (creative thinking). (interview with Rob 24 September 1990)

These teachers' beliefs were reflected in the learning processes in the class which encouraged the majority of students to develop higher-level inquiry skills.

In this class, where the discussion between teacher and students had become an integral part of the program, students constantly negotiated meanings, and argued their ideas in a whole-class forum under the leadership of the teacher. During these discussions students also supported their ideas with data recorded by scientists in the database. As a result of this type of inquiry learning, which falls within the framework of constructivism, these students were able to generate higher-level questions and design complex investigations to challenge their own questions. On the other hand, in the class in which discussions were not an integral part of the program, the majority of the students tended not to develop these types of higher-level inquiry skills.

The paper presents clearly the importance of student discussions in developing higher-level thinking skills. In the two classes, students were able to give various interpretations to the same problems, and designed different investigations. In the Grade 12 class, students were involved in discussions and they successfully developed their analytical inquiry skills. They demonstrated understanding of the database by constructing hypotheses to explain their interpretations, and developing further data retrieval to support their hypotheses.

The field notes and interviews revealed interesting ideas of how students generated questions. This was mainly presented through class discussions and interviews with students. The type of questions generated by the students changed drastically from narrow informative questions at the beginning of the program, to creative questions which was not confined only to the content of the database at the end of the program. The students demonstrated a variety of questions which reflected their development of higher-level thinking skills.

CONCLUSIONS

This paper discussed how the learning program, *Birds of Antarctica*, and the associated curriculum materials, helped students construct higher-level thinking skills. The paper clearly shows that the program was effective in facilitating students' development of inquiry skills, as measured by the Inquiry Skills Test. The learning processes and teaching approaches in Grades 11 and 12, influenced the nature of the higher-level thinking skills and the extent of their development.

Practical Skills

The paper discussed early constraints that students encountered while they interacted with the database. Those small groups of students who could not overcome the constraints of practical skills were not able to engage in developing higher-level thinking skills. The data obtained from classroom observations and interviews revealed that students who had acquired a reasonable proficiency with the practical skills developed higher-level inquiry skills more readily than did students who were not proficient.

Students need to develop the prerequisite practical skills of learning the database language and visually understanding the database, in order to develop higher-level inquiry skills of interpreting graphs, constructing hypotheses and testing their viability, and constructing questions through creative thinking.

Higher-Order Inquiry Skills

The study clearly establishes the importance of the teacher's role in facilitating students' development of inquiry skills. The teaching styles of the two teachers discussed in the paper were based on different epistemologies. The Grade 12 teacher's epistemology was constructivist in nature, whereas the Grade 11 teacher's epistemology was transmissionist in nature. Teacher epistemology shaped the learning processes in the classes and influenced the nature of the higher-level thinking skills and the extend of their development. This was revealed by the interpretive earch methodology. In the Grade 11 class, the teacher's transmissionist approach to teaching and learning resulted in students being less involved in discussions and making less sense of the database. Most of these students did not demonstrate abilities to generate creative questions, or to design complex investigations while engaged in the computerised database.

The Inquiry Test results for Grade 12 showed significant gains in the three areas of investigation. Students in the Grade 12 class developed higher-level inquiry skills mainly because they were involved in negotiating meaning in group discussions. In this class, where the learning was more closely aligned with a constructivist approach, students were able to generate higher-level questions and design complex investigations using the computerised database. The discussions enabled students to make better sense of the database and influenced the development of higher-level thinking skills.

The Inquiry Skills Test showed significant improvement in students' performance in interpretation, analysis and application for each of the two classes, but did not differentiate between the two classes in terms of the nature of higher-level thinking skills and the extent of their development. Major differences in developing higher-order inquiry skills were identified through the classroom observations and interviews during the study and described in this paper. The next phase of this research will attempt to further identify the differential nature of development of inquiry skills in the two classes.

REFERENCES

Bigum, C. (1987). Without walls. Geelong, Victoria: Deakin University.

Cziko, G. (1989). Unpredictability and indeterminism in human behavior: Arguments and implications for educational research, Educational Researcher, 18 (3), 17-25.

Driver, R., & Oldham, V. (1986). A constructivist approach to curriculum development in science. Studies in Science Education, 13, 105-122.

Driver, R. (1990). Constructivist approaches to science teaching. Paper presented at University of Georgia, Mathematics Education Department.

Erickson, F. (1986). Qualitative research on teaching. In M.C. Wittrock (Ed.). Handbook of research on teaching (3rd edition). New York: Macmillan.

Ericsson, K. A., & Simon, H. A. (1984). Protocol analysis: Verbal reports as data. Cambridge Massachusetts: MIT Press.

Fraser, B. J. (1979). Evaluation of a science-based curriculum. In H. Walberg (Ed.) Educational environments and effects. Berkeley, CA: McCutchan.

Fuhrman, M., Lunetta, V.N. , Novick, S., & Tamir, P. (1979). The laboratory structure and task analysis inventory (LAI): A users' handbook (Report No. 14). Iowa City: University of Iowa.

Kuslan, L., & Stone, H. (1969). Teaching children science: An inquiry approach. Belmont, California: Wadsworth Publishing Company.

Nachmias, R., & Linn, M. (1987). Evaluation of science laboratory data: The role of computer presented information. Journal of Research in Science Teaching, 24 (5), 491-506.

National Research Council (1989). Everyone counts: A report to the nation on the future of mathematics education. Washington, DC: National Academy Press.

Oliver, R. & Okey, J.(1986). Using computer simulations to promote achievement and transfer. Research in Science Education, 16, 191-198.

Papert, S. (1988). The conservation of Piaget: The computer as grist to the constructivist mill. In G. Forman & P. B. Pufall (Eds.) in the computer age. New Jersey: Lawrence Erlbaum Associates.

Prawat, R. S. (1989). Teaching for understanding: Three key attributes. Teaching and Teacher Education, 5, (4), 315-328.

River, R. H., & Vockell, E. (1987). Computer simulations to stimulate scientific problem solving. Journal of Research in Science Teaching, 24, (5), 403-415.

Schwab, J.J. (1963). The biology teaching handbook. New York: John Wiley & Sons.

Stake, R. & Easley, J. (1978). Case studies in science education. Urbana, IL: Center for Instructional Research and Curriculum Evaluation, University of Illinois.

Tobin, K.G. (1990). Social constructivist perspectives on the reform of science education. Australian Science Teachers Journal, 36 (4), 29-35.

Tobin, K. & Gallagher, J. (1987). What happens high school science classrooms? Journal of Curriculum Studies, 19, 549-560.

Young, L. S., Sykes, G., Featherstone, J., Elmore, R.F., & Devaney, K. (1990). Tomorrow's schools: Principles for the design of professional development schools East Lansing, MI: Holmes Group Inc.

Weiss, I. (1987). Report of the 1983-86 national survey of science and mathematics education. Research Triangle Park, NC: Research Triangle Institute.

Zohar, A., & Tamir, P. (1986, Fall). A new instrument to assess the inquiry characteristics of science computer software. Journal of Computers in Mathematics and Science Teaching, 44-46.