From Surprise to Cognition: Some Effects of the Structure of
C.A.L. Simulation Programs on the Cognitive and Scientific
Activities of Young Adults

R.J. Dicker

In partial fulfilment of the requirements for
the degree of Doctor of Philosophy,
University of Surrey.
1984
Summary

The main objective of this thesis is to describe the effect on cognition of the structure of CAL simulation programs used in science teaching. Four programs simulating a pond ecosystem were written so as to present a simulation model and to assist in cognition in different ways.

Various clinically detailed methods of describing learning were developed and tried including concept maps (which were found to be summative rather than formative descriptions of learning, and to be ambiguous) and hierarchical structures (which were found to be difficult to produce). From these concept maps and hierarchical structures I developed my Interaction Model of Learning which can be used to describe the chronological events concerned with cognition.

Using the Interaction Model, the nature of cognition and the effect that CAL program structure has on this process is described. Various scenarios are presented as a means of showing the possible effects of program structure on learning. Four forms of concept learning activity and their relationship to learning valid and alternative conceptions are described.

The findings from the study are particularly related to the work of Driver (1983), Marton (1976) and Entwistle (1981).
In this thesis, concept learning is regarded as a personal construction of knowledge resembling C.S. Peirce's notion of scientific methodology. Results seem to indicate that cognition follows the perception of a "surprising" event by the creation of a reasonable hypothesis (concept), by the deduction of the consequences of this hypothesis, and by the comparison of observations with predictions to either confirm or refute the hypothesis.
Acknowledgements

The seemingly short time that I have been carrying out this research has resulted in a change in how I view science, teaching and educational research. I hold less dogmatic views being aware of alternative conceptions. My re-education has been a pleasurable experience. I have enjoyed the long hours ploughing my way through masses of data in an attempt to understand how the students I observed were learning through the use of a computer program. I have become, according to my wife, a "workaholic".

The Institute of Educational Development at the University of Surrey must take a large proportion of the credit for enthusing and guiding me through the many hazards that can befall research students. My thanks go to Professor Lewis Elton for accepting me as a student and for reading the lengthy draft reports and early editions of this thesis; to the members of the Personal Construction of Knowledge Group (PCKG) for providing stimulating thought; to Dr. Diana Laurillard (now of the Open University) for providing the early guidance I needed at the start of my research; and not least of all to Dr. Maureen Pope for taking me on when Diana left, and for providing the support when I needed it, the readings in psychology and education, and the kind comments during the preparation of this thesis which I knew meant that changes were required!
Support throughout the last four and a half years from my family has allowed me to carry out this work as well as a full-time job teaching. Not having to do the washing up and not having to put the children to bed at nights has freed a lot of time in the evenings! My thanks and love go to my wife for providing this supportive atmosphere and for doing the little jobs that make my life easier. I hope that knowing how I grateful I am will help to repay some of the lost hours which we, as a family, could have spent together.

Finally, any research project requires research material. My "research material" were students in the Department of Science and Electrotechnology. To those students who volunteered to take part in these studies, I can only express my thanks. Without them there would be no research findings! I hope that they have gained from the experience. For many of them it was their first experience of using a computer. I hope that they have passed from Surprise to Cognition.
## Contents

### Summary

### Acknowledgements

### Contents

#### PART ONE  GENERAL INTRODUCTION

<table>
<thead>
<tr>
<th>Chapter 1</th>
<th>Introduction and Literature Review</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The Development of Computer Based Learning</td>
<td>3</td>
</tr>
<tr>
<td>1.2</td>
<td>What is Computer Assisted Learning?</td>
<td>12</td>
</tr>
<tr>
<td>1.3</td>
<td>Evaluation Studies</td>
<td>21</td>
</tr>
<tr>
<td>1.3.1</td>
<td>The Evaluation of Educational Innovations</td>
<td>21</td>
</tr>
<tr>
<td>1.3.2</td>
<td>The Evaluation of CAL</td>
<td>23</td>
</tr>
<tr>
<td>1.4</td>
<td>Review of Theories of Learning</td>
<td>32</td>
</tr>
<tr>
<td>1.4.1</td>
<td>Behaviourist Theories of Learning</td>
<td>33</td>
</tr>
<tr>
<td>1.4.2</td>
<td>The Cognitive Theories of Learning</td>
<td>35</td>
</tr>
<tr>
<td>1.4.2.1</td>
<td>Gestalt Psychology</td>
<td>35</td>
</tr>
<tr>
<td>1.4.2.2</td>
<td>Guilford's Structure-of-Intellect Model</td>
<td>36</td>
</tr>
<tr>
<td>1.4.2.3</td>
<td>Piaget and Developmental Psychology</td>
<td>38</td>
</tr>
<tr>
<td>1.4.2.4</td>
<td>Neo-Piagetian Psychology</td>
<td>45</td>
</tr>
<tr>
<td>1.4.2.5</td>
<td>Other Theories of Cognitive Structure</td>
<td>46</td>
</tr>
<tr>
<td>1.4.2.6</td>
<td>Expertise-The Purpose of Education?</td>
<td>55</td>
</tr>
<tr>
<td>1.4.3</td>
<td>Styles and Strategies of Learning</td>
<td>59</td>
</tr>
</tbody>
</table>

| 1.5        | Computers - An Advance in Educational Technology? | 63 |

#### PART TWO  THE DEVELOPMENT OF THE MAIN RESEARCH THEME

<table>
<thead>
<tr>
<th>Chapter 2</th>
<th>Research Methodologies and Techniques</th>
<th>66</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Introduction</td>
<td>68</td>
</tr>
<tr>
<td>2.2</td>
<td>The Computing Hardware</td>
<td>72</td>
</tr>
<tr>
<td>2.3</td>
<td>The Students Participating in the Research Studies</td>
<td>75</td>
</tr>
<tr>
<td>2.4</td>
<td>Pilot Study Research Methodology and Techniques</td>
<td>76</td>
</tr>
<tr>
<td>2.4.1</td>
<td>Students</td>
<td>76</td>
</tr>
<tr>
<td>2.4.2</td>
<td>The Objectives for the Pilot Study Learning Activities</td>
<td>78</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Use of EVOII</td>
<td>79</td>
</tr>
<tr>
<td>2.4.4</td>
<td>Tutorial</td>
<td>80</td>
</tr>
<tr>
<td>2.4.5</td>
<td>Research Techniques for Pilot Studies</td>
<td>81</td>
</tr>
<tr>
<td>2.4.6</td>
<td>Evaluation of Student Learning Activities</td>
<td>82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.5</th>
<th>Main Study Research Methodology and Techniques</th>
<th>84</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5.1</td>
<td>Aims</td>
<td>84</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Reasons for Choice of Ecology as the Topic Area for the Main Study CAL Programs</td>
<td>86</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Research Techniques for the Main Studies</td>
<td>89</td>
</tr>
<tr>
<td>2.5.4</td>
<td>Evaluation of Student Learning Activities</td>
<td>93</td>
</tr>
</tbody>
</table>
## Chapter 3 Pilot Study Results

### 3.1 Introduction

3.2 Comparison of the Effectiveness of EVOLU and a Tutorial

#### 3.2.1 Overview of Methodology

#### 3.2.2 Protocol Analysis

##### 3.2.2.1 Method

##### 3.2.2.2 Validation of Protocol Analysis

##### 3.2.2.3 Analysis of Student Activities in Tutorials

#### 3.2.3 Results

3.3 A Comparison of the Learning Activities Generated by Different CAL Programs

#### 3.3.1 The CAL Programs

#### 3.3.2 Methodology

#### 3.3.3 Results of the Comparison of Cognitive Activities Encouraged by Different CAL Programs

#### 3.3.4 Conclusions

3.4 A Comparison of a CAL Program and a Laboratory Exercise

#### 3.4.1 Introduction

#### 3.4.2 Methodology

#### 3.4.3 Results

##### 3.4.3.1 Design of Pendulum Apparatus and Performance of Experiments

###### 3.4.3.1.1 Stewart's Experiment

###### 3.4.3.1.2 Nariman's Experiment

###### 3.4.3.1.3 Comments on the Pendulum Expt.

##### 3.4.3.2 Use of PENDULUM

#### 3.4.4 Comments on the Comparison of a Simulation and a Laboratory Exercise

#### 3.5 Implications for the Main Studies

## Chapter 4 The Development of the Main Study CAL Programs

### 4.1 Introduction

4.1.1 The Construction of Models

4.1.2 The Design of CAL Programs

### 4.2 The Development of the Main Study Programs

#### 4.2.1 POND-2

#### 4.2.2 PONDQU

#### 4.2.3 PONDGAME

#### 4.2.4 POND2HELP

---

-vi-
Chapter 5  The "POND" Programs as a Teaching Medium
  5.1 Introduction  
  5.2 Student Perceptions of the Aims of the "POND" Programs
      5.2.1 Methodology  
      5.2.2 Results  
  5.3 Student Preferences for Data Presentation
      5.3.1 Introduction  
      5.3.2 The Presentation of Numerical Data by the POND Programs  
      5.3.3 Student Preferences for Scientific Data Presentation
          5.3.3.1 Introduction  
          5.3.3.2 Methodology  
          5.3.3.3 Results  
      5.3.4 Recommendations for Data Presentation in CAL Programs  
  5.4 Development of the Food Pyramid Concept: Initial Findings  
  5.5 Student Views of Teaching the Concept Food Pyramid  
  5.6 Conclusions and Comments

PART THREE  CONCEPT LEARNING: IT'S NATURE AND FORMATION IN THE CONTEXT OF CAL

Chapter 6  The Nature of Conceptual Knowledge: It's Acquisition and Representation
  6.1 Introduction  
  6.2 Conceptions of the Concept "Concept"  
  6.3 The Acquisition of Concepts  
  6.4 Alternative Conceptions  
  6.5 Conceptual Exchange  
  6.6 The Structure of Knowledge?  
  6.7 Representations of the Structure of Knowledge - A Pedagogic Aid?

Chapter 7  The Development of Concept Maps and Hierarchical Structures as Techniques for Describing Learning
  7.1 Introduction  
  7.2 Concept Maps
      7.2.1 The Development of Concept Maps for Students Using the POND Programs  
      7.2.2 The Success of Concept Maps in the Analysis of Chronological Episodes in the Learning Process  
  7.3 The Elucidation of Hierarchies  
  7.4 Concept Maps and Hierarchical Structures as an Evaluation Tool
PART ONE

GENERAL INTRODUCTION

In recent years, computer technology has been applied to the learning needs of those attending various educational and training establishments, the range of which extends from first school to university level, from handicapped to "normal" establishments, from vocational and training establishments to academic institutions. Such a range of use has meant that there has been an increasing need for programs and supporting literature.

The need for software has been met in a number of ways extending, for example, from those individual teachers who produce their own software, to groups of individuals involved in the production of a program or series of programs. These people may have different areas of expertise: some may be subject experts, others having experience in presenting the subject material using the computer, others may be skilled in writing computer programs.

The result of these activities has been the production of a plethora of programs of varying quality. One only has to examine the catalogue of a program distribution agency such as the "Central Program Exchange" based at Wolverhampton Polytechnic to realise that there are many areas in which a large number of similar programs have been written. This plethora of programs, however, cannot be the concern of this study of computer assisted learning (CAL).
This dissertation is concerned with the educational quality of CAL software with respect to those user activities that are associated with learning. Programs vary markedly in their quality, in their complexity and their subject depth. Many programs are written with what appears to be little concern to the educational outcome of using that program. Little thought, for example, appears to be given to the flexibility of the program in adapting to the individual's "conceptual base", to the individual's learning needs, and to the individual's preferred learning style.

In part one of this dissertation I want to review and examine not only the various ways in which computers can be used in education, but also how various educational innovations, including CAL, can be evaluated. I will also review some of the more important theories of psychology of relevance to cognition and to concept learning in particular. It is only through an understanding of how various factors affect cognitive activities that program design will be generally improved and that programs will be designed to encourage specific cognitive activities.

The area of CAL of most concern in these studies is that of simulation programs for use in science education. In using a science simulation program, a person can be said to be using the computer as a laboratory. The program user is acting as a scientist, creating and testing hypotheses. Scientific activities can be regarded as a special subset of concept learning activities, activities in which rigour and objectivity is being applied. Part one thus includes a review of some of the more significant theories and philosophies of science and scientific methodology and tries to show their relevance to concept learning.
Chapter 1.

Introduction and Literature Review

1.1 The Development of Computer-Based Learning

At the present time, computers (and especially microcomputers) are being widely used for a number of purposes by schools, colleges, universities, industry and commerce. The importance of computers to education is such that the U.K. government has funded a number of projects related to computer based learning (CBL) during the last decade. The government initially recognised the role of computers in education by establishing a five-year National Development Programme in Computer Assisted Learning (NDPCAL) in 1973. NDPCAL's brief was to stimulate CAL at all levels of education. However much of the work carried out throughout the U.K. was concerned with CAL at university or college level. When the NDPCAL project ended in December 1977, the Council for Educational Technology (CET) received financial support to carry on the coordinating function of NDPCAL for a further four years. This financial support did not, however, include funding for any new development work. The CET undertook the responsibility of setting up a national catalogue of CAL and CML materials, and of running seminars and conferences to bring the CAL community together at regular intervals.
With the invention of the "silicon chip" or microprocessor, computers became much smaller, cheaper and thus more widely available to the financially less privileged educational establishments, ie. the schools. The importance of all aspects of the microprocessor revolution were recognised by the government who did not wish for the U.K. to lag behind other countries in the development of its applications. They thus introduced the "Microelectronics Development Programme" in 1980.

The Microelectronics Development Programme is concerned with all aspects of the "chip" including microelectronic devices, microcomputers and their applications such as CAL. In addition, the CET were asked by the DES to consult H.M. Inspectorate, the National Council for Special Education, the School's Council and other organisations and to put forward proposals for work in special education (ie. for the deaf, blind and physically handicapped).

Within the programme, local courses were run for teachers to introduce them to microcomputers (especially the Research Machines 380Z microcomputer and more recently the BBC microcomputer), programming and computer based learning. These teachers were meant to return to their schools and disseminate the information they had obtained to enable larger groups of teachers to become "computer aware". However, although each school participating in the project were able to buy a microcomputer at discount, it has proved difficult for these schools to buy sufficient numbers of microcomputers to enable them to be widely used in their schools. It is the stated intention of the programme that the children are intended to get at least one session of "hands-on" experience of computers during their time at school, rather
than for the microcomputers to be a regularly used educational tool.
In some ways this is an undesirable situation for schools, especially
those in the primary sector. It is a situation which schools find
difficult to prevent for financial reasons.

Mechanical aids, such as the computer, to learning have been recognised
for a considerable time by certain educators and educationalists.
R. Goodman (1963) in a foreword to a book concerned with programmed
learning made certain comments that would be almost as applicable to
the use of computers today as it was at that time to teaching machines.
It is worth examining a considerable amount of what he had to say in
this foreword:

"The idea of using machines to teach what we need to learn,
the idea that we should automate part at least of the
learning-teaching process is opposed by many educationalists.
The main reason for this is that the case for
auto-instruction or programmed learning has frequently been
poorly presented. It has been claimed that teaching by
machine would be a universal panacea for all our educational
difficulties. But this it certainly is not. It has been
presented in fact, if not in intent, as a gimmick. And
serious educationalists naturally, and rightly, are
suspicous of gimmicks. It has been presented, with
significant exceptions, as tied to a particular psychological
theory - usually some form of behaviourism - which, for
various reasons, is unacceptable. But this, too, though in
the main historically true, is false in fact.... The case for
programmed learning and for teaching machines is not a simple
one. It is not simple because it must be based on a
fundamental, and frequently disturbing, analysis of the role
of education, of the function of the teacher, and of concepts
and theories current in western Society. Indeed, whether
auto-instruction is ultimately widely adopted or not, the
impact of the idea cannot but be salutary in that, maybe for
the first time, it compels us to think seriously and
critically about learning and teaching, and about what we, as
human beings, want of our world. And this, of course, is
the source of much of the opposition to teaching machines,
for, in the face of such an analysis, we who teach must be
prepared for the destruction of much of that irrational
mystique which is our classical refuge and the cloak behind
which we so often dissemble."
The history of programmed learning apparently extends back into antiquity with devices such as the abacus acting as teaching, as well as adding, machines. However, the development of a teaching machine, as we know it today, did not start until Thorndike had an idea that a mechanical device, which presented small chunks of information at a time, could be used to take over from personal instruction. However, Thorndike's idea was not taken up until the 1920's when Pressey at Ohio State University designed such a device. However, this device worked by presenting a predetermined sequence of multi-choice questions, which the student attempted to answer. This design was not a revolutionary one for education, and did not become generally accepted in the classroom. Skinner's teaching machine was developed in the 1950's. This machine presented a carefully sequenced set of material to a student. This was the start of an era, the era of machine-based learning which is still in existence today with the extensive use of computers in schools, colleges and universities.

Skinner's (1958) programs were designed according to the concept of "linear programming" where a body of information is broken down into a sequence of small steps leading logically through the subject. Each step, or "frame" may be regarded as a sequence of stimuli. Each frame shares common elements with both the previous frame and the frame to follow (see figure 1.1).
Figure 1.1 Representation of a linear sequence of frames as used in Skinner's teaching machines.
These elements are known as discriminative stimuli because, as the student proceeds from the known to the unknown, they ensure that the probability of a correct response is increased. An important feature of linear programming is that the student writes down or constructs his own responses which is thought to make the student think more deeply about the material and enable them to gain a greater understanding than would be possible from the use of multiple-choice responses. Linear branching programs do not, therefore, test the student but teaches him by requiring him to make a positive, thoughtful and free response.

It is interesting to note that the techniques emerging from Skinner's studies of learning were not designed to "develop the mind" or to further some vague "understanding" of mathematical relationships. These, however, are the very objectives that the developers of CAL simulations believe are important for their program and packages.

Norman Crowder's work (Crowder, 1958), concerned with simulator-based training, led to the development of a method of programming known as branched programming. Here remedial sequences are provided when an error is made by the student. Unlike Skinner's teaching machines, Crowder's presented much larger chunks of information in a frame. Crowder believed that it is an insult to a student's intelligence to present small amounts as linear programs do. In branched programming, a frame of information is presented and is followed by a multiple-choice question which has to be answered correctly before the student can progress to the next frame. If the answer given is incorrect then the student is told so and is also told the likely nature of his mistake. He is then redirected to the original frame to make another attempt or to a remedial sequence before returning to the
original frame or the one succeeding it (figure 1.2).

Figure 1.2 Representation of a branched sequence of frames as used in Crowder's teaching machines
Goodman (1963) predicted the future development of machine-based learning:

"The next step now becomes clear: available machines presenting branched programmes are inadequate because they fail to provide for branching on more than one parameter - the response of the student to the most recently presented information-quantum. - This is another way of saying that they are not really adaptive. One obviously wants the student to branch on the basis of a whole set of parameters, of which his response history over at least a previous sub-sequence of the programme, and his own assessment of his understanding, would be two. But this necessarily involves the evaluation of decision functions which only a computer can perform efficiently."

A third method of programming was devised by Gordon Pask (Pask, 1961) which met Goodman's wishes. Pask believes that it is impossible to devise an adequate program for teaching manual skills without taking into account changes of attitude and the periods of interest and fatigue which occur during the course of learning. Pask therefore developed machines which "learned" the behaviour pattern of students and which constructed their own programs on the basis of this information.

Pask's teaching machines are known as "adaptive teaching machines" and use Adaptive programming. This form of programming depends on the student making errors, and as such the difficulty of the subject material is controlled by the machine to maintain a certain error level. Pask's machine records student's performance in terms of his speed and accuracy and so it builds up a picture of what the student finds most difficult. Obviously, the recording of such information and the use of this information necessitated the use of a computer incorporated into the machine. This marked the introduction of computers into education and training.
The "programmed learning" or "teaching" machines were optimistically seen as an effective replacement for the teacher in the classroom. However, these teaching machines did not live up to the expectations many people had for them. McKeachie (1974) believed that teaching machines were a disappointment since they were based on inadequate laws of learning (Thorndike's Law of Effect or Reinforcement, for example). These laws failed to recognise the differences between humans. The teaching machines failed to motivate the students. They were found to be boring by the students.

With the availability of computers to educational establishments, the teaching machines soon disappeared from the classroom. The type of program used in these machines was converted to the forms of software which could be used by this novel introduction (the computer) to teaching. The programs could run faster than in the mechanical teaching machines. Unlike students who had used the teaching machines, students using the computer consoles, for what could now be called CAI, were found by Oettinger (1969) to have:

"...impressive levels of intensity and concentration."
1.2 What is Computer Assisted Learning?

Computer Assisted Learning (CAL) can be taken merely to be the use of computers in education. This term would thus encompass any use of the computer to assist learning by students. It could be the use of the computer by the teacher to record student marks and by their analysis highlight topics where student success has been poor. This might necessitate a new approach, for example, to be taken by the teacher in presenting the curriculum material to the students. It may be the use of the computer to present information in a given order to the student; to present simulations of laboratory experiments or of real-life situations. It could be students using the computer in a tutorial mode.

However, "Computer Assisted Learning" can be taken to have a more specific meaning. Many phrases have been developed in recent years to describe specific uses of the computer in education and training. One of the broadest, and the one which should have perhaps been used to describe the various uses of the computer indicated above, is Computer Based Learning (CBL). Within CBL are entailed a variety of more specific uses of the computer:

i) Computer Managed Learning (CML) uses the facilities of the computer to record assessment marks, and even present tests to students within a single course or a number of courses, to present the teacher with information about a student's current status, that is the units, modules which have been successfully completed. CML also allows courses to be compared, perhaps one year with another at the same academic level. It could perhaps perform a "Big Brother" role in that it could assess one teacher's results against those of another teacher.
or against a "norm". Many people believe that OIL could be one of the biggest areas of use for computers. There is no doubt that by assisting the teacher, by relieving him/her of much of the tedious and time-consuming administrative work, more time can be devoted either directly or indirectly to their students.

ii) Computer Assisted Instruction (CAI) is probably the major use of the computer in educational establishments in the U.S.A. However, in the U.K. it is less widely used. CAI is a natural development from systematic training and programmed instruction carried out using "Skinnerian boxes" and "teaching machines" respectively. Programmed instruction, although heralded as a major advance for the classroom, did not survive for very long. Many say that it was based on a theory of learning falsely extended from animals such as pigeons to humans. Programmed instruction has made many of the teachers and educators in the U.K., who saw its introduction, wary of any of the more recent technological advances such as CAL and CAI. However, CAI is thought to be a more suitable way for the student to learn than programmed instruction.

With instructional forms of education, the main objective is the retention by the student of information presented by the computer. CAI allows a student to progress through a program in a variety of ways depending upon their success at each stage. Some of the more simple programs, when recognising a mistake being made will route the student to exercises to reinforce the subject area not understood, and then continue the program when that student has shown an understanding of the material. More complex programs, and I believe, more advanced programs, have different routes through the subject material depending
on the capabilities demonstrated by a student, as for example, in the "Enhanced Tutorial Programs" described by Ayscough (1980) where the route is dependent on the student's current and previous responses.

Pask (1969) describes the monitoring of the student's progress and the presentation of suitable subject material as a "teaching strategy". The computer in CAI can therefore be regarded as being a substitute for the teacher, and is being used as a means of accomplishing individualised learning. The emphasis in CAI is not so much on a demonstrable understanding of the subject material, but on its rote memorisation.

Cooper (1980) felt that all "tutorial" applications of computers represent "good" educational computing. He believes that in tutorial applications we have progressed far beyond the teaching machine and programmed text stage. However, he also felt concern in that they do little more, at best, than ape the activities of good teachers, and may, in fact, do far less and warns:

"If this is all that we can achieve, we should perhaps forget these applications and concentrate on areas where the machine can perform a real function of which a human teacher is incapable, for example, simulation packages. It is not sufficient for packages to be cheap, error-free and popular with students. They must possess some demonstrable value in pedagogic terms and very few of us have achieved this."

By suggesting that tutorial-style programs are not necessary since teachers can usually do better than the computer is, in my belief, a little short-sighted. They have a role to play in education. There are times when help is required by students, for example to revise a previously taught topic in remedial situations. By having alternative teaching media and materials available, a teacher can be well equipped to accommodate the needs of his/her students.
Programs must have a demonstrable value in pedagogic terms. Many programs lack such a clear and demonstrable value. Many are produced by the cottage-industry of teachers working in their spare-time. These teachers have little supportive knowledge of how the programs will effect learning in their students. The programs are often merely written to present a certain "package of knowledge" in computer program format.

iii) Although a student using a CAI program can be said to be learning by using the computer, I believe a more subtle definition of CAL is available. CAL can be regarded as the use of the computer to enrich a student's understanding of a particular subject or topic. The emphasis here is not on rote memorisation of material, but on the relative freedom of a student to become immersed in the subject material.

"Once one gets 'inside' a theory, it starts to seem 'right'...The subjective experience is one of insight and it engenders a feeling of truth - the in-sight rapidly becomes an out-look"  
(Head and Sutton, 1981)

The emphasis is on the student being able to say "what happens if...." and then being able to find out the answer using the CAL program. Probably, therefore, the most useful and fruitful use of computers in education for students are simulations, models of the real-world or even a fictitious world.
McKenzie (1977) describes the meaning of CAL as the:

"...use of the computer as a powerful tool, mainly as if it were a laboratory, providing a learner with simulations, and the opportunity to do problem-solving and undertake calculations."

Zinn (1978) describes this form of CAL as "learning with the computer", Atkins et al (1977) as "revelatory" types of CAL. The computer allows the student to experiment, to "get the feel" of the simulation model. By becoming involved with the model, previously acquired knowledge becomes experiential and thus understood more deeply by the program user.

There are many other reports in the literature concerning the benefits or advantages of CAL. Harding (1979) reporting on the beneficial use of CAL in the teaching of applied mathematics at Cambridge University said that there was a:

"positive appreciation by students... and a considerable benefit in terms of examination marks."

The benefits that accrue from the use of CAL in terms of examination marks probably arise from the unique characteristics of CAL. These unique characteristics of CAL have been described by McKenzie (1977) as:

(i) an immediate feedback by the computer which maintains interest by the student,
(ii) the weaker more introvert student becomes an active participant in the learning process,
(iii) the computer is a patient participant,
(iv) the interactive graphics makes it possible to sample many more illustrations than could easily be shown in a textbook,
(v) mathematical calculations can be done as readily for the realistic examples as for the artificially simple cases that can be solved analytically,

(vi) large volumes of data can be handled with accuracy and without drudgery,

(vii) the use of the computer is a novel techniques (to many of the students) which provides enrichment to a course through added variety.

McKenzie's description of the advantages of CAL as a teaching and learning medium can be summarised as being a "unique means of producing data and by interesting (motivating?) a student by requiring the student to be an active participant in the learning process". The nature of the student's participation is to reply to specific questions posed by the computer, to see what happens as a result and to draw conclusions, hypotheses etc. based on these activities. Without some form of active participation, the computer program would not be able to proceed. The program would stop at the INPUT statements.

In response to the data INPUT by the student, the computer responds by carrying out calculations and then presenting data in a variety of forms such as text, table, graph or a pictorial representation or display. This display of data is intended to convey some form of meaning to the student. It is meant to convey a representation of the behaviour of the simulation model contained within the CAL program.
This sequence of events, that is INPUT to OUTPUT to INPUT etc. can be regarded as a sequence of episodes in a conversation. Such a sequence of events might thus look like:

**COMPUTER:** Asks question(s) to initiate a process.

**STUDENT:** Replies to question(s) — perhaps a YES/NO reply, the INPUT of parameter values, or perhaps by a short dialogue.

**COMPUTER:** Progresses through the program on the basis of the student's previous replies. May display data (results) as a consequence of these actions.

**STUDENT:** Views data. Makes observations.

**COMPUTER:** Asks for another set of parameter values.

This looks like a transcript of a conversation between two people. Because of the identity of the two participants it is often known as the "Student-CAL interaction". Pask (1976a) sees this interaction process, or conversation, as the means by which the student learns.

According to Laurillard (1981) the secret of a good CAL package is that it:

"...focuses the student's attention on salient features of the subject matter and encourages him to engage in the type of cognitive activity that will facilitate learning."

Laurillard's description seems to say concisely what most people involved with CAL see as the benefits of CAL to education.

One often reported benefit of CAL is the "novelty" of using a computer known as the "Hawthorn Effect". As microcomputers become more common not only in educational and training establishments, but also in the home the Hawthorn effect might become less noticeable. The
popularity of "personal" microcomputers is rarely due to an academic interest in computer science or the use of the computer to aid learning and understanding of academic subjects. These microcomputers are often used to play games of varying sophistication.

However, CAL is not the panacea for teachers to help overcome all of the difficulties that are encountered in learning subject matter.

There have been a number of "warnings" published in the literature concerning the use of CAL packages. Hebenstreit (1974) warns that the use of computer simulations might turn into a game situation. However, he did go on to say that the interactive use of CAL programs should help to raise the level to an intellectual one rather than merely one of playing. Also, it seems that "playing" a game might also be a useful motivational aid to learning (Malone, 1981). Thus this form of program should not be dismissed too quickly from the educational catalogues.

The CAL program developer must be aware of the inherent danger of producing trivial programs. It is relatively easy to write a simulation program related to a particular topic, as a glance at the published lists of programs will show. It is more difficult to write a good CAL simulation program which engages the student meaningfully in a particular range of cognitive activities.

McKenzie (1977) describes other instances when the CAL program may not be effective in promoting student learning, namely:
i) a program may give an unexpected response to an unusual input,

ii) some students are intimidated by the computer and prefer to look over the shoulder of other students,

iii) overuse, for example using a program longer than one hour can lead to boredom. Crovello (1974) actually goes further than this and says that the overuse of a program by a student can hinder the development of analytical skills,

iv) without a perceived goal, the package will not be properly appreciated. Cox (1976) extends this point by saying that a written introduction (i.e., package notes) can prevent the student from floundering when the topic is an unfamiliar one.

An additional factor which can hinder learning is the situation where the package does too much (Laurillard, 1981). This overextension by the program may be because the programmer is trying to use the computer to its full capacity, for example, to give a complete demonstration of some complicated system.

It thus seems that CAL programs and packages can form useful addition to the "repertoire" of teaching aids that a teacher has available. However, much careful thought must be given to the development of a CAL program so that it leads to a useful and interesting learning experience for the students. Program developers require, therefore, a knowledge of how program structure can affect student learning if a well-designed program leading to the desired range of cognitive activities is to be the end-product. This means that suitably designed evaluation studies must be performed, and that a knowledge of cognitive psychology is necessary to understand the learning processes being exhibited by users of CAL programs.
1.3 Evaluation Studies

1.3.1 The Evaluation of Educational Innovations

Until recently, educational innovations have been largely evaluated and compared according to a nomothetic approach. This approach has made use, for example, of matched groups, the selection and construction of appropriate objective tests, pre- and post-testing, item analysis, reliability checks, piloting of questionnaires etc. Malcolm Parlett (1977) calls this the "Agricultural Botany Paradigm". It is the methodology by which this type of scientific experiment is designed and by which the data is analysed for its significance.

In recent years it has been recognised that there are many difficulties associated with this form of evaluation. Difficulties such as the large number of students required and the amount of oversimplification that it is necessary to impose, the fact that a lot of useful information can be missed especially in complex situations such as classrooms and similar learning milieu.

As a consequence, "illuminative evaluation" has evolved to take account of the wider contexts in which educational programs function (Parlett and Hamilton, 1977). According to Parlett and Hamilton, the primary concern of illuminative evaluation is with description and interpretation rather than with measurement and prediction. This form of evaluation, as a research strategy is adaptable. Different techniques can be used to throw light on a common problem.
With illuminative evaluation, the researcher starts by being concerned with a wide area of interests. This breadth is reduced during the period of enquiry so that more attention can be paid to those areas which become more apparent in that they seem to be important issues in the study. Such a research strategy can easily be criticised in that it relies heavily upon the subjective judgement of the researcher. Parlett and Hamilton (1977) partially counter this criticism by arguing that any research involves skilled judgements on the part of the researcher, that illuminative evaluation data should be cross-checked (Parlett, 1977); and that it portrays accurately what the researcher knows. Parlett said that:

"...presenting a recognisable reality is a major means of validity testing in illuminative studies."

Evaluation by means of case-studies is a reaction to the nomothetic evaluation techniques. A case-study is a detailed observation of an instance. The descriptions are supplemented by interpretation. As Hawkins (1979) stated, the purpose of this evaluation technique is so that:

"Educational decision makers are...able to share the experience of innovation undergone by others."

Case studies are a useful way of examining the totality of the situation being observed. However, since case-study work is time-consuming it necessitates a relatively small sample size when compared to other evaluation techniques. Because of the individuality of each case-study, it means that a strict comparison between case-studies is not possible although the evaluator can use his/her own judgement to make comparisons, much in the same way as H.M.Inspectorate used to inspect schools using their own professional judgements. Evaluation data from various sources such as from case-studies,
questionnaires, surveys and from experiments help to construct a more complete picture of educational practice and should be regarded as being complementary (Entwistle, 1981).

"It is therefore to be expected that sometimes evaluation will be viewed as measurement, sometimes as professional judgement."

(Hawkins, 1979)

1.3.2 The Evaluation of CAL

CAL, as with any other educational innovation, has been evaluated by a variety of methods. Oettinger (1969) whilst referring to the lack of evaluation that CAI was receiving at the time, commented that:

"Intuition and anecdotal evidence do not support the optimism necessary to continue experiments."

It thus seems as if Oettinger was not satisfied by early forms of illuminative evaluation, but was looking for the numerical and statistical approach to evaluation that had been common practice until that time. A student's performance with programmed instruction or CAI packages has often been carried out in the past using pre- and post-tests to determine the amount of factual knowledge that has been acquired.

Pask (1969) when reviewing various methods for the evaluation of CAI, commented on various difficulties that were being encountered:
"The fundamental difficulty is that no one really knows what to measure (as evidenced by the fact that vast amounts of latency and response data have been collected on tapes, though very little of it has been used for evaluation). Just as the functional evaluation of an educational subroutine calls for a learning theory (which amongst other things, tells the experimenter what to measure) so the evaluation of an entire CAI system calls for an educational theory. At the moment no adequate theory exists..."

Later in this paper, Pask goes on to describe developments in the theory of education that were taking place. Educational psychology was moving away from behaviouristic models of learning to models which are generally accepted nowadays, that is to say, the various cognitive theories of education. This demand for change in evaluation attitudes was made at about the same time as CAL was beginning to emerge as a promising and viable aid to learning.

CAL expects more from a student than rote memorisation. It requires the student to be an active participant in a heuristic method of teaching. If the process of learning is accepted as a personal construction of knowledge (see 1.4) then whatever a student acquires during a learning experience cannot be described merely by determining the knowledge acquired program determined by the use of pre- and post-tests (Laurillard, 1977). Pre- and post-tests have other limitations for CAL:

"This form of testing is not CAL specific. The tests do not reveal the uniqueness of the potential of CAL." (Kemmis, 1977a).

Laurillard (1977) believes that it is not possible to plan a systematic testing programme and that the evaluation procedure has to reflect the exploratory nature of the development by using open-ended techniques such as interviews and observation.
In the CUSC project (Laurillard, 1977), a variety of evaluation techniques were tried. Four techniques were finally found to be of value. These included: (i) observation schedules, (ii) student feedback forms, (iii) questions within the package, and (iv) interviews. Techniques (i), (ii) and (iv) allow a general description of the learning outcomes of the program to be determined. In other words, the processes of learning are investigated through the student's experience of it.

These evaluation techniques should, however, allow more than a "general description of learning outcomes" to be determined. Students using a CAL simulation program or package should be experiencing and becoming aware of the behaviour and responses of the model implicit in that program. Rules, laws and concepts are produced by the student in an attempt to understand, describe, understand and predict the model's behaviour. In a scientific context, these laws, rules and concepts are ideally tested by the student. The ideal student will perform experiments using the computer model to see whether their hypotheses or predictions are correct. An evaluation of CAL must therefore examine not only the learning of "facts" but should also determine the various cognitive activities demonstrated by a student, including those associated with scientific methodology whilst using a CAL program. In this way, it is possible to describe how learning occurs and thus the factors affecting learning in the context of CAL.
More emphasis in CAL is placed on "knowing how" rather than "knowing that". "Knowing how" includes Bloom's higher cognitive activities (Bloom, 1956) such as comprehension, application, analysis, synthesis and evaluation. It is, therefore, not unexpected to find that many evaluators of CAL have used descriptions of student activity similar to those of Bloom.

There are two notable typologies which attempt to describe the various cognitive activities which might be demonstrated by a student using a CAL program. Namely those of Kemmis (1977a) and Laurillard (1978a).

<table>
<thead>
<tr>
<th>Kemmis' typology</th>
<th>Laurillard's &quot;types of learning&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognition</td>
<td>1. Becoming aware of</td>
</tr>
<tr>
<td>statements.</td>
<td></td>
</tr>
<tr>
<td>concepts.</td>
<td></td>
</tr>
<tr>
<td>principles.</td>
<td></td>
</tr>
<tr>
<td>or Intuitive</td>
<td></td>
</tr>
<tr>
<td>understanding.</td>
<td></td>
</tr>
<tr>
<td>7. Constructive</td>
<td>8. Checking knowledge and</td>
</tr>
<tr>
<td>understanding.</td>
<td>understanding.</td>
</tr>
<tr>
<td>8. Checking knowledge and</td>
<td></td>
</tr>
<tr>
<td>understanding.</td>
<td></td>
</tr>
</tbody>
</table>

By observing students using CAL programs, the educational potential of CAL programs can be described in terms of the learning activities that it can generate. These descriptive terms are those of the Student-CAL Interaction, and are similar to Rothkopf's (1966) notion of "mathemagenic activities".
The descriptions of the various cognitive activities are descriptions of episodes in the learning experience of the student using the CAL program. These episodes may be composed of shorter component episodes entailed within the main episode(s). It may be asked, for example, what constitutes an episode shown to be "reasoning" or "experimenting"? Kemmis and Laurillard have made very little attempt at examining the nature of these activities as encouraged by the CAL program. That is to say they have made little attempt at examining the structure of CAL programs and relating this to the type of detailed learning activity it generates. Laurillard (1978a) recognises this limitation of current research. More needs to be known about the exact nature of these cognitive activities and how they are promoted by CAL programs.

In his studies of student learning, Kemmis (1977b) has made some attempt at describing a method which can be used to elicit how the structure of a CAL program can affect learning activities. This interaction between the CAL program and the student is shown by Kemmis as a "data matrix":

- 27 -
Context (elements of the boundary between the organism and environment through which they engage and interact.

Figure 1.3 Data Matrix Model (Kemmis, 1977b)
Although Kemmis believes that the interactive process between the student and the CAL program is a continuous one, he feels that it is necessary to attempt to describe it in an episodic manner.

The CAL program structure and content must control, to some extent, the activities of a student using that program. This program structure controlling a student's activities Kemmis calls its "functional structure" or "f-structure". At any one time the f-structure which defines the context within which the student is working, will affect the student's actions illustrated by the way he interacts with the computer and by what he says.

By examining the data matrices Kemmis believes it should be possible to see any developing pattern of interaction brought about by the program. The pattern of interaction that Kemmis believes will develop, he calls the "activity structure". However, no published account or description of actual data matrices nor of activity structures has been produced. Even so, Kemmis thought that they will be more useful for the evaluator of CAL than a description of the developing cognitive structure.

There seems to be several criticisms that can be made of this type of description of the interaction between the student and the CAL program, namely:
(i) No attention is paid to the student's preconceptions, that is his conceptual structure existing before using the CAL program. Prior knowledge and experience can be important in determining, at least in part, the "functional-structure" or context within which the student is working whilst using a CAL program.

(ii) The data matrix model almost presumes to regard the process as being behaviouristic in nature. That is to say, a "stimulus-response" process. Kemmis does, however, attempt to overcome this by saying that f-structures are not descriptions of the environment independent of the organism. They are meant to be descriptions of the boundary between the organism and the environment through which they engage and interact.

(iii) The data matrix thus seems to be a simplistic representation of the interaction process in that factors such as personal learning style are not included.

It is, however, the only model published which attempts to explain the PROCESS of the Student-CAL interaction (and the consequential learning that occurs). An attempt is being made here to examine the effect that the structure of a CAL program has on the learning behaviour of a student.

Pask's conversation theory of learning (1976a) is a more comprehensive tenet from which to work. The conversation theory was developed in an attempt to investigate the learning of realistically complex subject matter under controlled conditions. It is a theory which is more applicable to CAI than CAL, but nevertheless, it does contain much which can be used to explain any form of learning, including CAL.
The conversation between the computer and student, student and computer, and the student and the observer is the basis from which evaluations of how learning takes place are produced. Pask's conversation theory recognises that the student is an active participant in the learning process more so than Kemmis' data matrix model. It recognises factors such as learning style which the data matrix omits.

Pask's theory see learning taking place through conversations. The conversation may be one of asking questions, presenting answers to questions, the presentation of information and so on. When both participants in the conversation are in agreement, then a topic about which they were conversing can be said to be learnt. It is this part of the theory that is more applicable to CAI than CAL, because in CAI and in programmed learning, a direct conversation between student and computer is taking place where the computer is monitoring the various responses of the student. In CAL, at present the computer does very little monitoring of the conceptual beliefs of the student, and to do so would require an "intelligent" system. This conversation theory has much to offer, in my opinion, for future models of the Student-CAL interaction, although I have not considered it specifically in my research.
1.4 Review of Theories of Learning

To understand how CAL programs influence learning, it is necessary to have an understanding of cognitive psychology. Some theories of learning have led to the development of teaching devices, others to curriculum innovations and development. Without an adequate psychological theory, the teaching device or other innovation will itself be inadequate (teaching machines, for example, were found to be inadequate because they were based on Thorndike's Law of Effect [McKeachie, 1974]).

Present theories of learning extend from behaviourist views through to the various cognitive views.

Behaviourists believe that learning occurs as a response to a particular stimulus. In other words, there is a stimulus (S) - response (R) bond (a S-R bond). It is these S-R bonds and the way other stimuli affect an S-R bond that the behaviourist is interested in studying.

Cognitive psychologists, on the other hand, believe that much of learning is controlled from within the brain. This activity within the brain not only includes the process(es) of learning, but also perception and attitudes. Through learning, cognitive structures might be built. Cognitive theories are restricted to learning by man, whereas the behaviourist (or connectionist) theories of learning also involve learning by animals. Cognitive theories see man being aware of his environment and being able to modify solutions to problems where and whenever it proves necessary to do so.
I intend to review the major learning theories and to comment on some of their applications to programmed learning and CAL. The major part of this section will be concerned with various cognitive theories of learning since I believe that they have more relevance to CAL.

1.4.1 Behaviourist Theories of Learning

Watson was among the earliest of the behaviourists studying both animal and childhood learning behaviour. He came to the conclusion that the more frequently or recently an S-R bond occurs, the more likely it is that a stimulus-response connection will be made. A person will produce a correct S-R pattern by a process of trial and error whilst trying to solve a particular problem. Any unsuccessful responses made in attempt to solve the problem will tend not to be repeated, and more successful responses made consequently all the more frequently.

Thorndike held somewhat similar views to Watson. His experiments were carried out mostly using animals such as chickens, cats and dogs. They also showed that a problem could be sometimes solved by trial and error. Following a successful attempt at solving the problem, it often became easier and quicker for the animals to solve that problem. From these experiments Thorndike produced his "laws" of learning. These laws were extrapolated, somewhat inappropriately from animals to man. By reinforcing a response by giving some form of satisfaction to the subject, he found that the response was more likely to reappear. Recognition of such a phenomenon led Thorndike to produce his "Law of
Effect" which stated that satisfaction serves to strengthen or reinforce S-R bonds.

Thorndike's second law, the "Law of Exercise", was an agreement with Watson's findings. This second law states that bonds are strengthened by the same stimulus-response coming together a number of times. However, exercise or practice is not enough. Thorndike believes that a knowledge of results must follow the response if reinforcement is to occur.

Although Watson's and Thorndike's work has application to programmed learning, CAI and CAL, the work of Skinner has made considerable contributions to these areas of learning. He observed the behaviour of animals in a box which would deliver a small amount of food when a correct lever was depressed.

As would be expected from the work of Watson and Thorndike, initially levers would be depressed by the animals by chance, or trial and error. Thereafter, however, the efficiency of the animal to obtain food rapidly improved. This behaviour of the animal he called "operant conditioning". The animal produces its own reinforcement by obtaining a food pellet whenever it depresses the correct lever.

Skinner believes that it is necessary to have "continuous reinforcement" (obtaining a food pellet whenever an animal presses the correct lever) in the early stages of conditioning; later in the conditioning process, when the animal has satisfied some of its desire for food it is necessary to have "intermittent reinforcement" (when the animal sometimes receives a reward, and sometimes it doesn't).
From these and other experiments with animals and humans, Skinner came to several conclusions about the conditions necessary for learning, most of which he later applied to programmed learning:

(i) steps in the learning process should be short and should grow out of previously learned behaviour,
(ii) in the early stages continuous reinforcement should occur, to be later followed by intermittent reinforcement,
(iii) a reward should follow a correct response as soon as possible following its appearance,
(iv) the learner should be given an opportunity to discover stimulus discriminations for the most likely path to success.

1.4.2 The Cognitive Theories of Learning

1.4.2.1 Gestalt Psychology

Wertheimer, one of the earliest psychologists to recognise the importance of the internal processes of the brain in learning, belonged to the school of Gestalt psychology. In Gestalt psychology, the study of perception is regarded as being of prime importance in the study of learning. In his studies, Wertheimer observed that "intelligent" animals such as chimpanzees would often solve a problem by an apparent "flash of inspiration" or "insight", although they had been initially trying to solve the problem by trial and error. This insight into the means by which a problem can be solved is not recognised by the behaviourists as being important, but for the Gestalt
school it is of ultimate importance. Gestalt psychologists also differ from Skinner's behaviourist theories in that they believe it better to learn by large steps rather than by small steps. By making large steps an overall view of a "package of knowledge" can be taken (the word "Gestalt" meaning "an organised whole").

After appearing in the 1930's, Gestalt psychology gradually diminished in its general acceptability in the 1950's and 1960's, historically to be followed by the behaviourist views of Skinner, for example. In the same way, Skinner's views were found wanting and were replaced by theories of learning which place more emphasis on the structure and functioning of the brain.

1.4.2.2 Guilford's Structure-of-Intellect Model

Guilford (1956) described a structure-of-intellect (SI) model of human intellectual abilities. This he envisaged as three-dimensional cubic model which contained 120 abilities falling into three categories:

(a) Those concerned with content - figural, symbolic, semantic and behavioural.

(b) Those concerned with operation - cognition (knowledge), memory, convergent and divergent production (reasoning), and evaluation.

(c) Those concerned with product - units, classes, relations, systems, transformations and configurations.

Guilford concentrated his studies mainly on the second of these categories, operations. The various operations were believed to exist in a hierarchical progression. The most basic operation was believed to be cognition, the most advanced to be evaluation:
Brunty (1978) has remarked on the similarities between Guilford's description of operations and Bloom's Taxonomy of Behavioural Objectives (Bloom, 1956).

Guilford considered in some detail the processes involved in reasoning. His conception of convergent and divergent reasoning or thinking has been found by other workers (referred to later) to be a useful means of describing and accounting for the various types of student learning activity, although alternative terms have been provided and the concepts extended in certain cases. Divergent production was described by Guilford (1967) as:

"...the generation of information from given information where the emphasis is on variety and quantity from the same source... Problems requiring divergent production may be loose and broad in their solutions, criteria for success are vague and may even stress variety."

Convergent production he described as:

"...the generation of information from given information, but problems involving convergent production are rigorously structured, with a narrow answer; criteria for success in convergent production are sharper and more demanding."

It can thus be seen that a potential fundamental difference between groups of people has been described. Convergent thinkers producing a logical conclusion, divergent thinkers producing a number of logical possibilities. It has been reported (Hudson, 1966) that differences in occupational preferences by people might be accounted for by their preferred mode of thinking. Hudson found that young adults who were
classed as divergers usually preferred art subjects, and that those who were classed as convergers usually preferred science subjects. In addition to the two categories of reasoning provided by Guilford, Hudson provided a third, an intermediate group of "all-rounders". This latter group, in fact, he believed to contain the greatest proportion of people (40%), whereas the other two groups each were thought to contain approximately 30% of the population.

1.4.2.3  Piaget and Developmental Psychology

It was with the work of Jean Piaget that a notable advance in cognitive psychology, and in research techniques associated with developmental psychology, were made. Piaget's work appears to have three main areas of educational significance:

(a) the matching of educational material to the "cognitive stage" of the child,

(b) the development of suitable teaching material which encourages the cognitive growth of the child,

(c) the recognition that learning should be an active process for the child and that the teacher should be a facilitator of learning.
Piaget was concerned with the developing cognitive structures which change with the age of the individual as they pass through childhood to adolescence and adulthood. The course of cognitive development is seen as hierarchical and partitioned into major developmental epochs known as stages, or as Piaget apparently (Flavell, 1963) preferred them to be described, periods.

The periods are of:

(i) sensory-motor intelligence, normally to be found occurring between the ages of 0 to 2 years,
(ii) preparation for and organisation of concrete operations, normally to be found occurring between the ages of 2 to 11 years. Commonly, this period of development is subdivided into a period of pre-concrete operations and one of concrete operations.
(iii) formal operations, normally to be found occurring between the ages of 11 to 15 years.

Each period is characterised as containing an initial period of preparation and a final period of achievement. During the preparation period, the structures defining the period are being formed and organised. During a preparatory period the individual's behaviour is unstable. However, gradually the various structures become more tightly integrated, organised and stable, and the final period of achievement, a phase of equilibrium, is attained.

The cognitive process is slow and gradual. An individual can assimilate, or construe, those things which past assimilations have prepared him/her to assimilate. There must be some sort of organisation which "makes the unfamiliar familiar". A new assimilatory structure must always be some variant of the last one.
acquired much in the same way as a new scientific theory which accounts
for anomalies not explained by previous theories, is often a variant of
those previous theories. These assimilatory structures Piaget called
schemata. One important characteristic of schemata is that they have
a tendency toward repeated application. Schemata are always
extending their field of application.

Actions performed by the individual constitute the substance of an
intellectual adaption. In infancy, during the period of sensory-motor
intelligence, the actions are relatively overt. As development of
the individual takes place, the intelligent actions become
progressively internalised and covert. In other words, the cognitive
actions gradually become more schematic and abstract, or internalised.
The schemata become broader in range, and organised into systems, or
operations, which, according to Piaget, are structurally isomorphic to
logico-algebraic systems.

It is thus obvious that, according to Piagetian theory, the behaviour
of the individual can be explained differently during their period of
cognitive development. The pre-operational child tends to operate
solely in terms of the phenomenal, before-the-eye reality. The
concrete-operations child is beginning to extend his thought from the
actual to the potential, by a process of extrapolation. "The possible
is a special case of the real". The formal operational child
delineates all possible eventualities and tries to discover which of
these possibilities really do occur in the present data. "The real
becomes a special case of the possible".
The way that a child thinks appears to develop through distinct stages as s/he grows up. The Piagetian notion of a hierarchical development of children through certain defined stages has been questioned, notably by Brown and Desforges (1979). These authors believed that any hierarchical notion must be examined for conceptual links prior to any empirical investigations. This Piaget and his co-workers did not do. Brown and Desforges believed that:

"Piaget's claim for a hierarchical sequence of development may be a definitional claim. The claim is so. Any discrepancies found must be attributed to method problems or performance variability. They cannot be taken seriously in appraising the claim or reappraising its basis."

So why has Piaget found it necessary to formulate a "stage" theory or model of child development? The alternative model to a stage model must be a model which views development as being a continuous process. A process in which skills are tried and tested over a period of time, and gradually incorporated into the store of previously "tried and tested" skills. Such a process would be "smooth" when viewed over a period of years, or even perhaps months. It is difficult to see marked changes in the display of achievement of cognitive skills unless such activities of the children are compared over a sufficiently long period of time for a significant change to have taken place in that child. Piaget, according to Flavell (1963), takes for granted the fact that considerable continuity lies behind or beneath the sequence of stages. He thus admits that behind the behavioural configuration defining one stage and that defining the next stage above, one can usually discern a number of intermediary, transitional steps.
"The degree of continuity, the number of such intermediary steps, varies considerably with the content studied, the frame of reference of the experimenter etc., and is not in itself a problem of primary importance for the developmental psychologist."

A change in "cognitive level" as observed by a Piagetian psychologist is an artefact, a product of Piagetian man, only seen when a child's development is observed over several occasions covering a sufficient period of time, and when the child's behaviour is observed for particular predetermined activities or skills (Driver, 1978). A "sufficient period of time" is that which allows a development of these predetermined cognitive skills to take place.

There is a great similarity between the way Piagetians view cognitive development in children, and the way ecologists view the development of a "new" ecosystem, such as a sand-dune on the coast developing eventually into either a woodland or a heathland.

In ecology, such an ecosystem is seen to become more complex with time, and changes in a series of "successions" which are brought about by the plants themselves in that ecosystem. The way in which ecologists view these changes is given, for example by Maurice Ashby (1963):

"Our understanding of vegetation is greatly helped if we can recognise a community as a stage in a particular succession or sere. We can then form ideas about its past history...about the direction in which it is likely to change in the future, and how the course of these changes can be deflected by human interference. Such information may be very important in applied ecology, where land utilisation is under consideration.

Of course the progress of a sere is often so slow that the sequence of changes must be partly built on hypothesis; by putting together in order the different communities regarded as stages in the sere, like using a number of snapshots to reconstruct the sequence in a square dance." 

(pages 163-4)
Here, in the description of the concept "sere", we can see similarities with the approach adopted by Piaget and Piagetians, namely:

(i) That understanding of a "system" can be helped by recognising communities (groups of skills).

(ii) That an understanding of the "system" can lead to the synthesis of a model which can then be used in a variety of ways. Such a use of the Piagetian model has been the work of Michael Shayer (1981) who has used the model in developing a theory for use in science teaching and for the production of forms of instruction of potential use in cognitive acceleration (the acceleration of a student from one cognitive level to a higher one). This work of Shayer will be described briefly in Chapter 11.

(iii) That the sequence of changes is partly built on hypothesis, that is by putting together the different "communities" regarded as stages in the "sere". Seral stages are recognised by ecologists by the "dominance" of a particular plant species in the ecosystem. The dominant species is the one that is exerting the most influence on the other species within that ecosystem. However, Piagetian stages, unlike seral stages, are determined by the emergence, and persistence, of a new type of skill seen as being more "superior", for example more abstract in the case of the stage of formal operations, than previous skills. Piagetians are viewing the cognitive development of a child through an "epistemic tube", in other words they are merely concerned with certain predetermined cognitive skills. Brown and Desforges (1979) take Piaget's formal descriptions as a "model of competence" and not a psychological theory.
The stages are meant to be a means to an end of understanding the developmental process. Flavell suggested it is a way of abstracting highlights within some frame of reference, from a panorama of gradual change.

"Different theorists will naturally differ somewhat in the stages they posit."

Brown and Desforges (1979) emphasise that:

"....to maintain that a child is in a particular stage is not particularly helpful unless you know on what tasks the assessment was made, and whether the tasks were adequate to make assumptions of a generalised ability."

(p.114)

The complexity of the task presented to the researcher demands that some economy be made in his observations. These observations normally being made of behaviour expected or predicted by a particular model.

Whether a stage model or a model of continuous development is a more accurate representation of cognitive development is important in curriculum development. Piagetian "stage theory" can result in a prescriptive form of education in that the progress of a child's education will be based on those contexts and characteristics seen as relevant in defining a stage. This aspect of Piaget's work often obscures more important aspects of Piaget's work, especially those concerned with encouraging conceptual growth through the use of suitable teaching materials, and with recognising the student as an active participant in the learning process.
Piaget's theories of cognitive development do not account for the process of learning, that is the processes of assimilation and accommodation. It merely, for example, describes the role of these two processes during a transition period between one stage and the next.

1.4.2.4 Neo-Piagetian Psychology

Pascual-Leone (1976) states that the conflict that exists, for example in the interpretation of Piaget-type data and the determination of the cognitive stages of children, can be resolved by the use of the idea of performance categories as functions of underlying competence which are dependent upon context for their demonstration.

Pascual-Leone, perhaps more importantly, also developed a model of the mental processing capacity of the child (Pascual-Leone, 1970). In this model he proposes that stage structure and equilibration should be regarded as quantitative constructs involving information storage and processing capacity. In this model, a "stage" is seen as an abstract structure. Pascual-Leone believes that this would allow intellectual development to be seen as an ordinal scale with the other dimension being the informational complexity of a given task as perceived by the individual. This allows a particular stage to be referred to by the amount of information that could be handled at any one time.
Brown and Desforges (1979) are uncertain as to whether Pascual-Leone's theory actually is an advance on Piaget's theory, although it does attempt to explain contradictions in the analysis of empirical studies. Within-stage development of children, according to Pascual-Leone's model, is a behaviourist model. Performance (response) at any stage is seen as being controlled by the amount of information which has been processed (stimulus). However, Brown and Desforges believe that Pascual-Leone's model is:

"...a highly promising development of Piagetian theory which can account for much of the challenging data...(eg. that on stage heterogeneity, horizontal decalage, and precocious behaviours)."

because it:

"...offers a maturational component..., an information processing orientation to task analysis and behavioural productions, a dimension for handling an important aspect of individual differences, and an account of scheme acquisition which, whilst apparently behaviourist, takes into account the structural constraints as 'hardware' limitations."

1.4.2.5 Other Theories of Cognitive Structure

Here, I want to look at some of the theories of cognitive structure that I think have importance for these studies. I do not intend to review all the major theories of cognitive structure. The theories that I will look at are some of those which attempt to look at the nature of knowledge, the way it is stored in memory, and their application to teaching. These theories include the work of Ausubel, Gagné, Vinacke, Pask and Lochhead. Much of Piaget's work which I described in 1.4.2.3 is concerned with the construction of knowledge by the individual, and is, therefore, related to the work I intend to review in this section.
Ausubel (1968) in his "subsumption model" believes knowledge to be acquired in a general to specific direction. In this model, an individual's cognitive structure is regarded as the main factor influencing meaningful learning and thus the retention of knowledge. Ausubel believes that if a cognitive structure is "clear, stable and suitably organised" it will result in the emergence of "accurate and unambiguous meanings". On the other hand, if the cognitive structure is "unstable, ambiguous, disorganised, or chaotically organised, it tends to inhibit meaningful learning and retention".

Ausubel believes that, in the past, theories had failed to recognise the importance of the cognitive structure variables. These theories had been preoccupied with noncognitive, rote and motor kinds of learning which had resulted in attention being focused on situational and intrapersonal factors such as practice, drive, incentive and reinforcement variables.

The important part in this model that cognitive structure plays in the learning process is the existence of specifically relevant anchoring ideas. These anchoring ideas allow new and logically meaningful material is to be learned and retained. In other words, the new material is subsumed within an existing structure. If such a structure does not exist, then the only alternative is rote learning which can lead to ambiguous meanings.
Ausubel proposed that it is necessary to introduce suitable "advance organisers" presented in advance of the learning material. Such advance organisers are of a high level of generality and may take the form of a summary of the material (if the new material was completely new and novel), or the way it differs and is similar to knowledge already subsumed within the cognitive structure.

Gagné (1962), like Ausubel, believes it necessary to present new learning material in an organised and meaningful context. According to Gagné's theories, both knowledge and skills are structured in a hierarchical manner but in a specific to general, or inductive, direction. Each skill is seen as having a subskill or a number of subskills prerequisite to it.

A point to note about these two theories is that knowledge is retained only if it is "meaningful". Johnson (1980) described meaningful learning as:

"...the relationship of new information to existing knowledge."

In this quotation there is an acknowledgement of the relationship between existing and new knowledge that these two models posit.

A comparison of the Gagné and Ausubelian models of learning leads one into the argument as to whether learning occurs through inductive and deductive processes. Gagné's model is compatible with inductive processes, Ausubel's model with deductive processes.
The argument for and against each of these processes occurs not only in cognitive psychology, but also in philosophies of scientific methodology. Popper (1980) denies the existence of induction, inductive processes or inductive inferences, and would thus argue against a specific-to-general model of the structuring of knowledge as proposed by Gagné. Popper argues that it is possible by means of purely deductive inferences to argue from the truth of singular statements to the falsity of universal statements.

Popper does not describe the mechanism or mechanism by which hypotheses are produced in the mind of the scientist creating new scientific knowledge. Popper sees the act of creation of new knowledge (a high cognitive level process in Bloom's hierarchy [Bloom, 1956]) as one which neither calls for logical analysis nor to be susceptible of it. However, this is one of the very activities that the cognitive psychologist is attempting to understand. Popper believes that every discovery contains an irrational element or a "creative intuition". C.S. Peirce (Fann, 1970), on the other hand, sees "creative intuitions" capable of at least psychological explanation in that they are reasonable hypotheses.

As a means of overcoming the dichotomy of Ausubelian and Gagné-type models of learning, it might be beneficial and fruitful to accept, at least in part, Vinacke's view. Vinacke (1952) comments that deduction is often the only observable process in formal syllogistic situations. He believes it might be better to regard deduction and induction as mutually operating activities. The inductive processes may be used to collect evidence relevant to the hypothesis. After appropriate analysis of the data, a generalisation may be reached which
either supports or rejects the originating hypothesis. Deduction, Vinacke hypotheses, may be introduced at any point along the line. Concept formation, he believes, can thus use both induction and deduction.

Arguments against induction being a valid means of concept formation are often based on the belief that observations are theory-laden actions. Observations are interpreted based on our past experiences. To perceive one must select events or objects. Prior experiences may teach one that it is useful or fruitful to attend to a particular event or object in a particular context. Thus the formation of a relationship between two successive events may occur because two similar, successive events have been seen to previously occur in close proximity either in space or time. It has thus been found fruitful to relate events that occur in such close proximity. However, relationships so formed may not always be valid. Deduction and hypothesis-testing may be important checks of the validity of concepts.

Vinacke sees learning and thinking as two separate processes. Learning he believes precedes thinking. Learning supplies the materials and the forms of thinking. Thinking, he believes is personalised being subject to the properties of the individual's cognitive structure which has developed according to the numerous and various past experiences of that individual.
It can be argued that the student's existing conceptual structure or knowledge base should form the starting point from which various learning experiences will progress. Such a viewpoint is held by the constructivist movement.

Learning can be viewed according to a bipolar construct where the poles are passive and active forms of learning. The constructivist notion of learning originates in Personal Construct Psychology (Kelly, 1955). According to this notion, learning is a "subjective, personal, active, rational and emotional affair" (Pope and Keen, 1981). This view is opposite to the behaviourist view, for example, where learning is seen to be the result of the transmission of views, beliefs and knowledge to a passive recipient.

According to the traditional view, learning is the accumulation of facts, the interrelationships and relevance of which may be seen at a later time. Constructivists regard learning as the creation of personal interpretations of the real world. Each person creates their own set of interpretations. Since the construct frameworks are individualistic, this notion of learning has been called "constructive alternativism". However, the nature of our interpretations are not fixed but can be changed if the individual believes it to be necessary. A person's constructs can thus be regarded as hypotheses in that they can either be refuted or maintained according to the information obtained by the individual. The purpose of these constructs, as with scientific hypotheses, is to predict and explain.
In applying the constructivist view to the teaching situation means that it is necessary for the teacher to understand the students' beliefs or constructs. It means that there should be a conversation between "expert" and "novice" in order that these beliefs can, in the first place be understood, and for conceptual shifts to be encouraged. Pask (1976a) sees learning as having taken place when agreement has been reached between the participants in the learning experience. These participants may be teacher and student, but may equally well be computer and student, student and student etc. Thus, in such a situation, the student will dictate the direction in which learning will take.

If individuals are recognised as being active participants in their own learning, the "teacher" might have to change his/her role to one of mentor, tutor or coach or facilitator of learning. One particular difficulty many teachers have in providing such a learning environment is in not understanding why students make certain mistakes or have misunderstandings because:

"What is seen through the pupils of the teacher's eyes can be so different from what is seen through the eyes of the teacher's pupils." (MacInnes, 1981)

It is only by understanding what each other's beliefs (constructs) are that influence can be brought to bear to cause a change in a person's interpretation of the real world.
The computer has been used as a model of the brain and its functioning in an attempt to understand the cognitive processes that take place during learning. The analogy between the computer and the brain is a common one nowadays.

Analogies between technological inventions by man and parts of the human body is not unique, as Jonathan Miller (1978) indicates:

"...the development of technology created a new stock of metaphors - not simply extra metaphors, but ones altogether different in their logical character....By mechanising his practical world, man inadvertently paved the way to the mechanisation of his theoretical world. The success of modern biology is not altogether due to the technology with which we pursue it; the number of technical images we now have for thinking about it play an almost equally important part....they have incidentally provided conjectural models for explaining the functions of the human body."

(pages 181-2)

In a similar way the computer has become, at least in certain areas, a convenient way of describing the brain. More specifically, in the area of Artificial Intelligence, computer programs are being written in an attempt to replicate and emulate the processes of the brain. Lochhead (1979a) has remarked that computer simulations of thought and clinical interviews have produced strikingly similar conclusions. These conclusions are of the important role that existing knowledge plays in determining how experience is perceived, and hence in how new knowledge is constructed.

Lochhead views learning in a similar vein to constructivists, that is the student is seen as an active participant in the learning process, and the most effective role of the teacher is one of tutor or coach to help the student to develop their own knowledge systems. It would seem possible, when computer technology becomes even more advanced and
more "powerful" for them to take on some of the duties of tutor or coach when suitably programmed. It would not only mean that the program would have to be versatile, but also intelligent in that it would need to model the knowledge, and perhaps the cognitive style, of a student in a way similar to that of a sympathetic teacher. The meaning of Computer "Managed" Learning would thus be different from the present-day meaning!

Artificial Intelligence has been described as "theoretical psychology". However, how near to the activity of the human brain the behaviour of the computer models are, or can become, is difficult to envisage. Even if the outcome of the program is identical with the outcome of a human brain in a similar situation, it would be difficult to say that the processes in both were, or were not, the same. L. Miller (1978) has criticised artificial intelligence for this very reason, that is, because this area of research has not produced theories whose adequacy can be tested by empirical research.

Supporters of artificial intelligence, however, might argue that it does allow representations, or models, of human problem-solving activities to be tested and used to aid, for example, the diagnosis of learning difficulties. Such a model might thus help to produce remedies of a student's behaviour in a learning situation. Models do not always have to be an accurate replica of a process, they merely have to be useful in a particular context.
Some of the findings of studies in artificial intelligence might thus prove useful in the design and construction of CAL programs to allow a flexibility of program use, but one whereby guidance can be provided according to the way the program is being used. Thus artificial intelligence can be extended into the field of "expertise" and "expert systems". I will consider these two concepts in the next section of this chapter.

1.4.2.6 Expertise - The Purpose of Education?

In education we are concerned with producing in our pupils a number of desirable characteristics. That is to say each education system has a number of broad educational objectives. Of course, such educational objectives may differ quite considerably with the philosophical viewpoint of the administrators of the system. One obvious objective, common to many, if not all, philosophical viewpoints, is that the individual becomes knowledgeable in a number of subject areas.

Larkin (1979) has looked at what makes an expert, and how individuals become expert. He believes that experts have much knowledge which is tacit (referring to Polanyi's concept of 'tacit knowledge' [Polanyi, 1969]). Tacit knowledge, of course cannot be passed on to individuals less expert other than by the expert being copied, mimicked or modelled by the novice. Such modelling of the expert can take place by observing the expert's actions and behaviour and then attempting to duplicate these actions.
Larkin sees expertise as the acquisition of sophisticated and complex "action and condition" units. Each unit consists of an action and the specific conditions under which that action can be taken, and as such are similar to Kemmis' "functional structures" (Kemmis, 1977b).

The response of experts and novices to a problem will be different. Larkin (1979) explains that experts initially use a low-detailed, often vague reasoning followed by more detailed reasoning. They appear to recall generalised principles. Novices, on the other hand, access the individual principles. Novices appear to have the impression that qualitative reasoning is an illegitimate activity in problem-solving. The blame for this belief is placed on the way material is presented in textbooks which, for lack of space, do not provide the qualitative reasoning.

It has proved possible to model some expert's using computer programs. Such a program (WUMPUS) has been produced by Ira Goldstein (1979). This type of program can not only be used to coach but also to diagnose any difficulties that may be encountered by the novice, but is mainly concerned with skill acquisition rather than with the acquisition of knowledge using high-level cognitive skills.

The purpose of education is not only to allow students to acquire factual knowledge and motor skills but also to encourage what has been described as "good habits of thought" (D'Amour, 1979). In other words, education encourages students to become skilled in the higher cognitive activities such as problem-solving and the creation of new knowledge and concepts.
Individuals will make mistakes on the way to becoming expert. They will often form "misconceptions" or "alternative conceptions" which are incorporated into their cognitive structure. The importance of studying misconceptions and alternative conceptions has been recognised in recent years.

In producing their own learning tasks students will determine what and how much they learn. Students shape the learning tasks on the basis of what they can bring to bear on the tasks as presented, for example, by a teacher or a computer program. They interpret the present situation against a background of past experience.

Students will obviously tackle a task provided in a number of ways. Sometimes they will not be able to construct a task because of insufficient past experiences upon which they can call to be able to successfully complete the task. In such a situation it has been suggested (Brown and Burton, 1978) that the student constructs new knowledge from their memory structure to deal with the "impasse" situation. Such new knowledge may not be accepted as valid by an "expert" and as such would be regarded as a misconception. This area concerning conceptual development is considered in greater detail in chapter 9 of this dissertation.

To construct new knowledge in such a situation might require a considerable amount of drive and motivation to overcome the immediate difficulty. A student who does not have this amount of drive and motivation will not complete the task and will be seen as being defeated, or failing, and leaving the problem unsolved.
Lochhead (1979b) has extended Brown and Burton's theory by saying that students need to construct multiple representations of knowledge. He said that students are often seen to oscillate between understanding and confusion whilst attempting to solve problems. These oscillations, he said, are recognised by any experienced teacher to be a fundamental characteristic of human learning. He believes that the oscillations are associated with the need to construct multiple representations of new knowledge and to test these representations against each other. Thus as one mode of representation has been mastered, the learner is apt to switch to another to broaden his grasp and thus enter a period of confusion.

Learning, thus, can be regarded as an active process dependent on the learner-defined tasks being affected not only by the character of the person, but also on their past experiences and previously established knowledge and beliefs. Personal strategies and styles of learning play an important part in determining the result of learning experiences and thus should not be ignored when considering CAL.
1.4.3 Styles and Strategies of Learning

Accounts of learning, especially those concerned with CAL, often place an emphasis on learning being "meaningful". Meaningful learning is regarded as an active process. If the learner is an active participant in the learning process, then this must imply that s/he must be operating some form of strategy concerning their understanding of the experience.

Various learning strategies have been described. Rothkopf (1966) has described the responses which give birth to learning in an individual as being their "mathemagenic" behaviour. Gagné (1977) believes cognitive strategies are internally organised skills that govern the individual's behaviour in learning, remembering and thinking. These cognitive skills and strategies he believed are learnt gradually. The acquisition of a variety of cognitive strategies will allow an individual to perform more and more cognitively difficult exercises. The strategy of an individual not only determines the range of evidence they are likely to use in the learning situation, but also how they obtain this evidence.

Marton (1976) sees learning as either being a "deep" or "surface" process. "Deep learning" he sees as something that a student does, and as a consequence, is more likely to understand the subject matter and see its relevance. To many people this would constitute "meaningful" learning. "Surface learning" occurs when a student is a passive participant in the process relying on rote learning rather than looking for meanings.
Pask (1976b) recognises that there are two basic types of learning strategy, the holist and the serialist. Holists are said to use much of the available evidence to construe their new knowledge. Serialists progress linearly through the concepts. Pask believes that holists tend to ask questions about broad relations, whereas serialists ask questions about much narrower relations.

Holism and serialism can be regarded as the extremes of a bipolar construct. They are thought to be manifestations of more fundamental processes induced by a "systematic enforcement of the requirement for understanding which is as strong as, or stronger than, the requirement for 'deep-level' processing".

The general tendency to adopt a particular strategy is known as a learning style. If the strict understanding condition is relaxed (as in class tuition or in self-study) some students tend to act "like holists" (these he called comprehension learners) and other students "like serialists" (these he called operation learners). There are some students who are able to exhibit both of these styles of learning quite successfully depending upon the subject matter, these people are said to be versatile learners.
Laurillard (1978b) has compared Pask's and Marton's dichotomous descriptions of learning, and concludes that the "process of learning" can be regarded as having two aspects:

(i) **Executive style** which refers to the way the student thinks about the subject matter. Pask's descriptions of "style" and "strategy" are included here.

(ii) **Strategic style** which refers to the way the student approaches the task. Marton's and Saljo's "levels of processing" are included here.

However, Laurillard warns that students cannot be classified using a dichotomous description of learning since they are responsive to the environment, their interpretation of the environment affecting their approach to learning:

"...it would be dangerous for an investigation of learning to be based on the assumption that learning is a process that is independent of other external factors, or that student's possess inherent, invariant styles of learning. It means that learning should be studied in the context in which it occurs, rather than in the laboratory..."

In studies of computer assisted learning, therefore, we should record the effect of interfering factors such as the presentation of the learning material, the student's strategic style, the effect of pre-established conceptual beliefs of relevance to the body of knowledge being presented by the CAL program.

Witkin (1976) argues, much in the same way as Pask, for the existence of underlying styles of thinking. Witkin recognises two opposite styles, field-independent and field-dependent. These describe a generalised approach to the learner's interaction with the environment, and their approach to the analysis of problem-solving tasks. A field-independent (FI), or analytic, person is able to analyse a
stimulus distinguishing, retaining and coordinating relevant items extracted from a distracting background. He analyses and structures incoming information. A field-dependent (FD) person is unable to structure a stimulus and to perceive its parts as discrete from the overall field of reference. He accepts the totality of impressions. The field-dependent person should thus be regarded as having a global style or quality which does not enable that person to discriminate between the object of primary importance and the surrounding distractions.

This categorisation of people into two groups which differ in their style of interaction with their environment by Witkin stimulated Douglass and Kahle (1978) to show that FD students perform more satisfactorily in (science) lessons based on a deductive presentation of materials, whereas FI students performed more satisfactorily when matched with inductive materials. However, I do not wish to be concerned at this point in trying to relate, in any detail, the nature of instructional or learning material with any theory of learning, instruction or cognitive style and strategy.

Entwistle (1981) has questioned the comprehensivity of the descriptions of preferred learning style. He believes that it may be of use in describing differences between students, but that the descriptions could be rendered more complete by recognising the differences that an individual student's strategic style may exhibit from task to task. In the context of CAL this would mean that the effect of the program, the effect of goals laid down in the package notes or by the teacher must be taken into consideration when the learning milieu is described.

The factors influencing learning are numerous. The influence of these
factors on learning involves a complicated interrelationship between the characteristics of the program user, the CAL program and with factors created in the "outer" environment, for example the classroom, in which the program is used. It may be more realistic therefore to view CAL not as a potential substitute for the teacher, but as an additional facility for learning.

1.5 Computers - An advance in educational technology?

Although many people nowadays have the notion that researchers concerned with programmed learning were essentially behaviourists, I think that this is a somewhat restricted and narrow view of their philosophies. For example, Thomas et al (1963) accepted the notion that the primary purpose of education is the "nurture of personal growth" and teaching as an "enabling process". They saw the teacher's task as:

"...guiding the student through experiences in a controlled environment, allowing him to form his own opinions, carrying out evaluations and make his own judgements." (page 3)

The teacher was not seen as dominating or obtruding into the process of learning but was seen as acting as a catalyst for the learning process:

"He should create an environment in which the student finds it very easy and interesting to learn, and should introduce order into the learning process to prevent it from being a haphazard and chaotic experience." (page 3)
However, although these educators had much of the philosophy of the constructivists (together with a behaviourist emphasis and an influence of Gestalt psychology) they believed it would be difficult to attain in our modern world. At that time, 1963, they criticised the education system for not carrying out enough educational research; for placing too great an emphasis on "teacher-teaching" at the expense of "learner-learning"; and for inefficient classrooms. However, they saw many of the problems being solved by modern developments in technology which would possibly allow a more:

"...effective communication whereby the student can be so stimulated that his education progresses at his optimum rate."

I think that very few teachers and researchers alike even nowadays would disagree, except perhaps certain "die-hards" in the system, with the closing statement of chapter 1 of Thomas's book:

"The problem facing the educationalist today is that of finding the best way of harnessing recent advances and achievements in science and technology in order to enrich the personal experience of his students, and so create an environment in which the accepted principles of learning can be realised."

(p. 4)

The emphasis in this quotation is not on using all recent technological advances to aid teaching and learning, but to select those which are going to lead to enrichment of a student's learning experiences.

Much can be done to improve learning programs whether they be of the tutorial type or the simulation type. Improvement can only come from an understanding of cognitive psychology and an understanding of how program structure affects student learning. It is also important to have programs which are "sympathetic" to the students' style of learning and the progress they are making whilst using the program. This means that research needs to examine in more detail learning theory as
directly applied to computer based learning, and how "adaptive" programs should be written perhaps using models derived from artificial intelligence (which will allow the student to be in some way, modelled and this model compared to a "desirable" model or models).

The development of programs must be based on a knowledge of what is required in terms of student learning, and how this can be achieved. It must mean some centralisation of program writing to avoid programs being written by those teachers unskilled in the necessary areas of psychology and student modelling.

The time for a number of exciting developments in CAL program design has arrived, and many of the programs written outside the "cottage industry" should begin to show a marked improvement in that they allow students the freedom to learn as they see fit, but also to receive guidance from the computer as and when seen necessary by the computer. Up to the present time, computers have provided a rewarding learning experience for students in a number of subject areas at different levels in the education system. However, teachers as a body have not yet accepted and realised the potential advantages for student learning of the various types of CAL program.

The possibilities for CAL become even greater with the introduction of the videodisc system. Linked to the interactive computer, much visual material can be presented to the student to act as backup learning material, especially in tutorial-style programs. The learning experience becomes more vivid and real, and thus of greater use for all teachers.
PART TWO

THE DEVELOPMENT OF THE MAIN RESEARCH THEME
PART TWO
THE DEVELOPMENT OF THE MAIN RESEARCH THEME

In part one I reviewed and described the relevance of various evaluative methodologies, psychologies of learning and some philosophies of scientific methodology to computer assisted learning and to cognition.

In part two of this dissertation I intend to show how the theme of the research studies changed focus from one which was intent on comparing CAL with learning in other milieu to one which concentrated on how CAL program structure can influence cognition. With a change in focus it became necessary to develop new evaluative methodologies. There was an apparent need in analysing Student-CAL interactions for a model of learning which recognised the effect of various intrinsic and extrinsic factors on that interaction process. The various techniques and methodologies used in these studies and the development of a suitable model of the Student-CAL interaction are described in chapter two.

The results of the pilot studies are described in chapter three. These results show that students use a CAL program somewhat differently from each other, and that CAL programs tend to promote a better understanding of a topic than a more didactic approach such as a tutorial.
Evaluations of CAL programs by various other workers have shown that each program has a potential to encourage a somewhat different "spectrum" of cognitive activities from other programs. These pilot studies also indicated this, and it was this that promoted the change in research direction.

With an interest in how program structure can affect cognition, it was necessary to produce a number of programs which, although using the same simulation model, presented that model in various ways. It was necessary to select a suitable topic area and a suitable CAL program in this area. This process is described in chapter four together with the features of the four "POND" programs produced for these main studies. A description of the general effectiveness, with respect to learning, of the POND programs is described in chapter five.
2.1 Introduction

In Chapter 1 the survey of the research literature has shown that little is known of the effect of program structure on learning activities. It is often stated that CAL packages enrich learning and promote intuitive understanding (see, for example, Laurillard [1978c]).

Any evaluation of the learning that takes place as a result of the interaction of the student with the computer must not prejude the nature of the learning that takes place (Laurillard, ibid.). Achievement tests are the type of assessment that do just this by prejudging the nature of the learning, by presupposing that the use of a package will increase the student's cognitive knowledge although this is not normally an aim of the package (Elton and Laurillard, 1979). Elton and Laurillard say that an achievement test would be unlikely to detect any measurable change in knowledge through the use of such a package.
Knowledge may be acquired either directly or indirectly by the use of a CAL package. It is well known, for example, that when a student first uses a computer it is a novel experience (known as the Hawthorn Effect). Experience has shown that these students often will spend more time away from the computer trying to solve problems, discover associated facts and so on, than they would have if they had been taught by "conventional" methods. If this novelty can be maintained then CAL may be a useful incentive for increasing cognitive knowledge. Perhaps that here there is an argument for the limited use of CAL.

With a CAL science simulation program, the computer acts as a substitute for a laboratory. One argument for the use of CAL as a replacement for a laboratory experiment is that many biology, and to a lesser extent chemistry and physics, experiments fail to give satisfactory results. The students often feel demoralised by this situation and can fail to see the purpose for carrying out a particular experiment. In addition, simulation programs can be used to allow a larger number of time-consuming experiments to be performed in a shorter period of time, to allow hazardous experiments to be performed without any danger to the student, to allow experiments to be carried out which in the real-world would be impossible or very difficult to do so.

According to Dowdeswell (1981) there are three main objectives for practical work in biology:

(i) To acquire a knowledge of certain basic techniques.

(ii) The verification and supplementation of information already acquired from other sources.
(iii) Using the method of guided enquiry to acquire first hand evidence for the solution of particular biological problems.

Although CAL cannot enable students to learn practical scientific techniques, it can allow them to become skilled in techniques of problem solving, hypothesis-production and testing etc. If, therefore, the CAL package is well designed, it can act as a replacement for many of the repetitive experiments that are performed by students.

A good example of a good simulation package are the series of experiments performed to "discover" the factors affecting enzymes and enzymic rate. Most of these are repetitions of a common and basic technique at which the student normally becomes skilled during the first run through of the experiment. The remaining experiments in the series, (for example observing the effect of pH, temperature, substrate concentration on product concentration) are normally concerned only with the collection of data to be manipulated by the students to illustrate particular concepts.

It should thus be possible for students to carry out the basic enzyme experiments to acquire the technical skills associated with the experiment, and then go on to use a suitable CAL package to become skilled in experimental manipulation, problem-solving etc. as well as obtaining the data which can be used to illustrate the appropriate concepts. This would mean that for the students the data obtained would be accurate, because there would be no error due to poor experimental technique. In this way, there might be an increase in perceived value of the laboratory exercise by these students.
Before using a CAL simulation in a teaching program, the teacher should be certain that:

(a) The CAL program has the potential to convey the desired body of knowledge,

(b) The CAL program is potentially as effective as alternative (more traditional?) methods of teaching used in the classroom and laboratory,

(c) The desired range of cognitive activities can be encouraged by the use of the CAL program. A decision should thus be made when designing the program concerning its pedagogic function. Is the purpose of the program to allow the behaviour of a model to be observed and understood? Is the purpose to encourage problem-solving or hypothesis formation and testing?

It was these three criteria which both the pilot and main studies were concerned with. The pilot studies are mainly concerned with criteria (a) and (b); the main studies with criterion (c).

Initially, in my pilot studies, I was concerned with comparing student learning in a number of very different milieu (in tutorials, laboratory practical sessions, and using CAL programs). It became evident from these pilot studies (see chapter 3), as I shall show, that a more detailed examination of learning under conditions more controlled than those used for the pilot studies was required.
The main studies were focused on observing and attempting to analyse the complex series of cognitive and "scientific" activities of students using a series of ecology CAL programs based on a common simulation model. Each of the programs differed in the methods by which they presented the information so that the effect of a differing program structure on learning could, at least partially, be determined.

2.2 The Computing Hardware

At the time of making the decision as to which computing system to use during these research studies, microcomputer sales were beginning to show a marked increase in the U.K. Commodore had introduced their PET "personal" computers aiming, I suspect, largely for the home market. It thus seemed appropriate rather than use a main-frame computer that I should use a microcomputer. I felt that many educational establishments in the school and college sectors would probably be able to afford a number of these, and thus they would become a more common piece of educational hardware. Another factor influencing my decision was that the PET microcomputer was portable and could be taken into classrooms and laboratories whenever it was necessary. The third factor influencing the decision was that it was becoming evident from articles being published in Commodore's own magazine, and indeed the popular computing magazines, that much additional hardware would become available to enhance the capabilities of this type of computer. This would mean that the microcomputers could become as powerful as many mainframe computers being used in CAL projects in the U.K.
The early PET's were stand-alone machines having an 8K memory and a cassette tape storage input. The programs for the PETs are written in Commodore Basic and are fully interactive since the input is through an integral keyboard and the output is on to a VDU (as an integral part of the microcomputer). The graphics on the VDU are of low resolution (40 x 25). Later, Commodore improved the basic design of the machine, the keyboard was increased in size to that of a normal type-writer size, a range of memory sizes (8, 16 and 32K) became available. A dot matrix printer was introduced which allowed a hardcopy of listings and program runs to be retained. Disc drives for "floppy disc" storage of programs were introduced which allowed a much faster rate of reading programs and data, and also allowed random or direct access files to be introduced as a means of storing and retrieving data on these microcomputers.

The main difficulty for those interested in producing CAL programs with a graphics mode of output was the low resolution screen. A "chip" was developed which increased the potential of graphics, allowing "double-density" graphics (80 x 50) to be used on the screen. Very shortly after this several types of "high-resolution board" were introduced which allowed the PET screen to be increased to a resolution of 319 x 199. In comparing this level of resolution to that possible on sophisticated main-fame computers the "high-resolution" graphics on the PET are merely "moderate-level" resolution. However, it allowed reasonable graphs, for example, to be produced, and removed the necessity of using poor, often confusing (see section 5.3.2.2), low resolution forms of graph to be output on to the screen. Later it became possible for the high resolution graphics boards to be modified to obtain a hardcopy printout of the screen contents.
8K PETs, with integral cassette decks, were used for the main studies, and for the early part of the main studies. Later as the programs were developed for the later stages of the main studies, it became necessary to have a microcomputer with a larger memory and one with better facilities than the early PETs. The later stages of the main studies were conducted on a Commodore PET model 4016 with a 32K memory, a model 4040 disc drive, a 3022 series dot matrix printer, and a Supersoft HR-40 High Resolution Graphics Board updated with a GRAPHICS WEDGE to allow hard-copies of graphs to be obtained. The whole system was placed on a trolley as the photograph below shows.
2.3 The Students participating in the Research Studies.

The research studies were carried out in the Department of Science and Electrotechnology, Guildford County College of Technology. The students participating in the pilot studies were attending a variety of vocational technician courses, namely the:

- Ordinary National Certificate (ONC) in Biological Science,
- Technician Education Council (TEC) Certificate in Science,
- Technician Education Council (TEC) Diploma in Science.

The ONC and TEC Certificate courses are part-time day and evening attendance courses for students who are employed as technicians in industry. The TEC Diploma course is a full-time course. For entry to all of these courses GCE Ordinary Level or CSE grade 1, 2 or 3 passes are usually required in science, mathematics and English language.

The age of students attending these courses was not determined but normally the students are between the ages of 16 and 19, although older students do sometimes attend the part-time courses.

The students participating in the main studies were full-time GCE Advance Level students studying biological subjects. This group of students were chosen because they are normally free for at least several hours during a day at least once every week. This meant that a student could use a CAL program and be interviewed immediately following their program run, all of which could take as long as two to three hours. Part-time students could not easily participate in this type of study since their time in college is taken with lectures and laboratory practical sessions.
in their studies, coming from the first, second and revision years of the course. A summary of the details of 35 students participating in these studies is given in appendix 1.

2.4 Pilot study research methodology and techniques

2.4.1 Students

The pilot studies attempted to compare the learning activities of students using CAL programs with those in different learning milieu such as tutorials. The TEC Certificate and Diploma groups were used in these pilot studies. The TEC Diploma class consisted of eight students, the TEC Certificate class consisted of nine students.

Each class was divided into two matched groups, that is of approximate equal academic quality based on standard scores calculated from assessment marks obtained throughout the current academic year of their course. The division is made by placing the students in order of academic ability according to their standard scores and then by placing alternate students (in their numerical order of academic ability) into each of the two groups. In practice, a better division seemed to be possible by assigning the students using their standard scores to each of the groups (1 or 2) as shown in figure 2.1.
To check that the two groups were not significantly different in overall academic abilities, the mean standard scores of the students were compared using the Students t-test for:

(i) for all subjects in their course,

(ii) for all biological subjects in their course.

<table>
<thead>
<tr>
<th>Course Group</th>
<th>Mean Standard Scores of Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEC Dip. 1</td>
<td>1.07 0.25 -0.17 -1.12</td>
</tr>
<tr>
<td>TEC Dip. 2</td>
<td>0.58 0.51 -0.24 -0.75</td>
</tr>
<tr>
<td>TEC Cert. 1</td>
<td>0.70 0.62 0.14 -0.12 -1.48</td>
</tr>
<tr>
<td>TEC Cert. 2</td>
<td>0.85 0.46 -0.16 -0.58</td>
</tr>
</tbody>
</table>

Figure 2.1 Standard Scores of Matched Groups of TEC Certificate and Diploma students for the pilot studies

| t-scores |
|----------|----------|----------|
| All subjects | Biological subjects |
| TEC Cert. (N=9) | 0.16 | 0.064 |
| TEC Dipl. (N=8)  | -0.021 | -0.211 |

Figure 2.2 Student t-scores for groups in TEC Certificate and Diploma courses

There appears to be no significant difference in ability between each of the groups so formed (see figure 2.2).
Biology II is a unit of study in both of the TEC courses involved in these pilot studies. This unit contains a section on evolution.

One learning objective in the section on evolution is described thus:

"Discusses the evidence for evolution by natural selection (including fossil evidence, evidence from comparative morphology, anatomy, embryology, physiology, and plant and animal geography) with reference to two detailed case studies, eg. the evolution of the horse and industrial melanism in moths."

(Biology II, unit no. 12 of TEC Certificate in Science Program (160200/77/09), Guildford County College of Technology).

This objective can be met, in part, by the use of an Open University program called EVOLU which requires the student to look at factors affecting the evolution of the peppered moth. This program was used by one group from each of the two classes, the second group of each class taking part in a tutorial concerned with the same topic area.

The study of the evolution of the peppered moth forms the final part of a lecture course on evolution, which for the TEC Diploma group consisted of:

1.25h of lectures on "Genetics for evolution"
3 h of lectures on "Evolutionary theories"
1.25h of lectures on "Evidence for evolution"
1 h tutorial or use of a CAL program as a means of providing a case study of the evolution of peppered moths.

The course for the TEC Certificate group was similarly arranged.
2.4.3 Use of EVOUJ

Students using EVOUJ were provided with a set of package notes (appendix 2) which outlined the development of industrial melanism in peppered moths, *Biston betularia*. It attempted to relate the appearance of dark, or melanic, forms of the moth to an increase in smoke pollution at the time of the Industrial Revolution in the U.K. Questions were also asked in the package notes in an attempt to encourage the students to think about what they were reading.

Following the introductory notes, instructions were given in the notes on the use of the computer and the program EVOUJ. It was suggested in these notes that the students attempt to show changes in the numbers of light, non-melanic, moths and dark coloured, melanic, moths in a number of environmental situations:

(a) A rural area,
(b) A rural area with a new industrial development,
(c) An industrial area,
(d) An industrial area becoming a smokeless zone.

The students were also asked to determine the effect of different mutation rates of the moth in the above four environments. Here it was expected that the students would select a high and a low mutation rate in either situation (b) or (d).
The tutorial was conducted by a biology lecturer at the college. The tutorial was introduced by this lecturer who explained the appearance of the two forms of the moth and how well they camouflaged with the bark of trees in various environments. The rest of the tutorial, in summary, covered moth predation by birds, the effect of pollution on population changes of the various forms of the moth, mutations, and Ketterwell's research of industrial melanism in the moths. In other words, similar information was presented in the tutorial as in the CAL package, EVOLU.
2.4.5 Research techniques for pilot studies

(i) The students using the computers were requested to work in pairs. One pair of each of the two groups (TEC Certificate and TEC Diploma) were observed using the program. The students' unspoken actions (for example INPUTs, the reading of package notes etc.), comments that they made to each other and to the teacher, and comments that the teacher (RJD) made to the students were recorded on protocol sheets (appendix 3).

(ii) Tutorials were organised by the teacher according to the topic area suggested, but no further assistance was given. The tutorials were thus presented by the teacher hopefully as he would normally do so. The tutorials were tape-recorded and later transcribed verbatim.

(iii) All students participating in these studies completed and returned a questionnaire (appendices 4 and 5) which requested their opinions of their experience with either the CAL program or the tutorial.

(iv) The students were interviewed in pairs either on the same day as the tutorial or use of the CAL program, or if this was not possible, on the following day. The interviews attempted to discover what the students had learned, the things that they had liked about the particular learning situation, or the difficulties they had encountered. All interviews were tape-recorded and later transcribed verbatim.
The students were asked to undergo an assessment one week following either their use of EVOWJ or after having taken part in the tutorial. The assessment (appendix 6) was of their understanding and recall of facts associated with the specific topic of industrial melanism in peppered moths. It attempted to compare the relative effectiveness of CAL and tutorials using a nomothetic approach.

2.4.6 Evaluation of student learning activities

Before any teaching or learning method can be compared, a suitable means of determining the learning activities of students must be available. The success of a particular teaching/learning method can be determined by describing each activity according to a typology such as that used by Kemmis (1977a) and Laurillard (1978a) specifically for CAL, and that of Bloom (1956) for all learning situations. It was felt that Bloom's taxonomy of cognitive activities had much to offer, subject to certain modifications, in the analysis of cognitive activities in these studies. The number of cognitive activities as suggested by Bloom was reduced by the condensation of similar activities, where appropriate, or by the elimination of activities which appear to be irrelevant to these studies. The list of cognitive activities produced (figure 2.4) consisted of twelve cognitive activities arranged in hierarchical order. Each cognitive activity was assigned a level, level one being the activity of lowest cognitive activity, and twelve of highest cognitive activity.
<table>
<thead>
<tr>
<th>Level</th>
<th>Description of cognitive activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Recall of material. Strategic decisions.</td>
</tr>
<tr>
<td>COMPREHENSION</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Translation - eg. graph, table etc. into words; measures and records data.</td>
</tr>
<tr>
<td>3</td>
<td>Interpretation - in that data is explained to show cause and effect.</td>
</tr>
<tr>
<td>4</td>
<td>Extrapolation - predicting consequences or effects by continuing a trend.</td>
</tr>
<tr>
<td>APPLICATION</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Selecting the appropriate enquiry skills when performing an experiment. Recognises the operation of some principle in a given situation.</td>
</tr>
<tr>
<td>6</td>
<td>Predicts the effect of change of a factor on a situation.</td>
</tr>
<tr>
<td>ANALYSIS</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Able to identify hypotheses, assumptions controls of a given experiment.</td>
</tr>
<tr>
<td>8</td>
<td>Hypothesis testing using experimental data.</td>
</tr>
<tr>
<td>SYNTHESIS</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Experimental design (to test hypotheses etc.)</td>
</tr>
<tr>
<td>10</td>
<td>Hypothesis formulation.</td>
</tr>
<tr>
<td>11</td>
<td>Interpretation - to discover new knowledge (as far as the student is concerned).</td>
</tr>
<tr>
<td>EVALUATION</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Makes judgements eg. evaluates accuracy.</td>
</tr>
</tbody>
</table>

Figure 2.3 Hierarchy of student cognitive activities based on Bloom's taxonomy of behavioural objectives.
Using this hierarchy of cognitive activities, the level of each of the activities demonstrated by students using EVOLU or during the tutorial could be determined and marked in the appropriate places on the protocol sheets. It was thus possible to show the progress of a student, or pair of students, through a particular learning situation in terms of the activities that were demonstrated. By determining the proportion of the activities at each cognitive level, it was possible to obtain an idea of the range of cognitive levels encouraged by the various learning milieu.

2.5 Main study research methodology and techniques

2.5.1 Aims

The main aim of these studies was to describe the effect on student activities including learning that the structure of a CAL program can have. The descriptions of learning occurring during the use of a CAL program provided by previous workers were not thought to be suitable for these studies for a number of reasons.

Although Kemmis' (1977a) and Laurillard's (1978a) typologies are useful in predicting the type of activity that a student using a CAL program might demonstrate, they make no attempt at relating the learning activity to what is being learnt by the student.
The development of a method which would be detailed, or clinical, in its approach to learning activity and to what appears to be learnt was, therefore, one of the essential prerequisites of these studies. The method produced would have to be open-ended in that it must be flexible to allow any unexpected events to be recorded (Laurillard, 1979). The development of such a method, the Interaction Model for describing learning is described in chapter 5.

In order to satisfy the main aim of this study, that is to determine the effect of program structure on learning, it was decided to take a published program and modify it in a number of ways. Such modifications were to include changing the format from a "normal" simulation program to that of a game, and to include questions and guidance.

An essential prerequisite for the use of a CAL simulation program, in my opinion, is for the program to be able to extend the horizons of understanding of the student in a way that no other type of teaching aid can. It must, therefore, be acceptable both to the student and to the teacher. These people must regard it as being efficient either in terms of time spent acquiring a "package of knowledge" or in understanding the simulation model. It was therefore necessary to use a simulation in a topic or subject area which would (i) be rich in opportunities for simulations, and (ii) one which would be conceptually difficult for the students participating in these studies.
It is necessary for the biology student to master a large number of concepts. Such concepts can include those of the cell, of life, and of homeostasis. Although most students find little difficulty in acquiring and understanding most of these concepts, there are a number of concepts which are traditionally found difficult. In an attempt to identify these "difficult" concepts, a search of the University of London's GCE triennial examiners' reports for Ordinary and Advanced level biological subjects between 1969 and 1978 was carried out.

The subject area of each question (or subquestion) was determined for each of the relevant examination papers. It was noted whether the examiners had found that the students had found difficulty in understanding the required subject material for that question. The combined results for all biological subjects (except human biology) of this survey are given in figure 2.4.

Several subject areas, specifically ecology and genetics, appear to be difficult for students studying biology. Johnstone and Mahmoud (1980) analysed the examiners' reports for the Scottish Certificate of Education between 1970 and 1978 and also found these two subject areas to be difficult ones. However, as Johnstone and Mahmoud commented in their paper, the criticisms of examiners must must be a function of question difficulty as well as of genuine weakness in student knowledge.
<table>
<thead>
<tr>
<th>Topic</th>
<th>&quot;O/L&quot;</th>
<th>&quot;A/L&quot;</th>
<th>&quot;O&quot; + &quot;A&quot;/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochemistry &amp; biological chemistry</td>
<td>4 (50)</td>
<td>9 (44)</td>
<td>13 (46)</td>
</tr>
<tr>
<td>Animal physiology</td>
<td>10 (30)</td>
<td>13 (85)</td>
<td>23 (61)</td>
</tr>
<tr>
<td>Animal types, anatomy etc.</td>
<td>21 (3)</td>
<td>19 (63)</td>
<td>40 (53)</td>
</tr>
<tr>
<td>Cell structure</td>
<td>1 (100)</td>
<td>2 (0)</td>
<td>3 (33)</td>
</tr>
<tr>
<td>Ecology</td>
<td>12 (58)</td>
<td>8 (88)</td>
<td>20 (70)</td>
</tr>
<tr>
<td>Evolution</td>
<td>0 (0)</td>
<td>3 (33)</td>
<td>3 (33)</td>
</tr>
<tr>
<td>Experimental data &amp; experimental design</td>
<td>4 (75)</td>
<td>5 (2)</td>
<td>9 (56)</td>
</tr>
<tr>
<td>Genetics (incl. cell division)</td>
<td>1 (0)</td>
<td>8 (88)</td>
<td>9 (78)</td>
</tr>
<tr>
<td>Microbiology</td>
<td>2 (100)</td>
<td>8 (63)</td>
<td>10 (70)</td>
</tr>
<tr>
<td>Plant types, anatomy etc.</td>
<td>5 (20)</td>
<td>7 (86)</td>
<td>12 (58)</td>
</tr>
<tr>
<td>Plant physiology</td>
<td>11 (64)</td>
<td>8 (88)</td>
<td>19 (74)</td>
</tr>
</tbody>
</table>

Key: In the above table, the number of questions the above topics are given, and the percentage of these found to be difficult for the students by the examiners are given in brackets following, eg. 4 (50)

Table showing frequency of topics in GCE "O" and "A" level biology examination papers, and the difficulty that the students have with each of these topics.
The difficulty students have with ecological topics might possibly be caused both by the conceptual difficulty of the subject area and the small amount of time that students study it. Sixteen year old biology students in the U.K. have very little experience of ecology besides that of a basic understanding of food chains, food webs and mineral cycles. Even eighteen-year old students do not extend their knowledge and understanding of ecosystems far beyond this (Booth, 1979).

Since ecology and genetics are both topic areas which lend themselves to having certain amount of their subject material being presented by a CAL program, the decision as to which CAL programs to use had to be based on somewhat different criteria. The decision to use a School's Council pond ecology program, POND-2, as the basis for a series of programs to be developed during this research programme was made because POND-2 was expected to encourage a much greater range of student cognitive activities, because of its breadth of subject content, than genetics programs concerned with calculating the results of crosses in various organisms.
2.5.3 Research techniques for the main studies

The main studies were concerned with examining the details of students' experiences using a simulation program. It was, therefore, necessary to use a somewhat clinical approach to the observation and analysis of the students. This, of course, is a time-consuming process which leads to the accumulation of mostly qualitative data. This meant that by adopting a case-study approach, a relatively small number of students would be involved compared to studies where a nomothetic approach is adopted.

However, by adopting a case-study approach I hoped that I would be sensitive enough to student behaviour so that the various important factors affecting their learning experience would become apparent.

Before using a simulation program the students were given a "pre-run" interview. The purpose of this interview was to ascertain their understanding of the main ecological concepts of the simulation model. Each student was asked:

a) To define what they understood by the term "food pyramid".

b) To imagine that they are a teacher who has to give a series of lessons in ecology, and to describe how they would explain a food pyramid to their students.

c) To give an example of a food pyramid?

The food pyramid concept is the central concept of the simulations used in these studies. Other concepts (for example that of equilibrium) are also necessary for a complete understanding of the simulations, but are less important.
By asking a student how they would explain a food pyramid if they were a teacher I expected the student to explain a food pyramid in a different way from that provided in their definition and/or indicate their preferred teaching method(s).

The third question was asked to determine whether their understanding of a food pyramid was correct. The provision of incorrect organisms or the omission of essential organisms (like photosynthetic plants) would indicate a difficulty in understanding of the food pyramid concept and thus the simulation model. An idea of the relative sizes of the populations is also required.

The pre-run interview was tape-recorded and transcribed verbatim.

Following the pre-run interview the students were briefly instructed how to use the computer. Additional help was available from the observer during the program run whenever it was absolutely required. The students were instructed to use the simulation program to "try and find out as much as they can about pond ecology". They were told that they could use the program for as long as they wanted to, that is until such time that they felt that they have acquired as much information as they could from the program.
The students were not allowed to become familiarised with the concepts of the program, that is by reading package notes before using the program. I felt that this was necessary because package notes might seriously influence the way that a student perceives the goals of the program. The effect of program structure, not package structure, on learning is of prime importance in these studies. My aim was to determine the "power" of programs in terms of the cognitive activities that they encourage. I believed it necessary to look only at the effect of program structure on learning because many students do not use package notes even when provided with them, or they tend not to use them as the authors of the notes would wish. In this kind of situation, the program should be powerful enough to accomplish what the whole package, in principle, is required to do.

In this type of research, much useful information and data may not be included because of the failure of the research subjects to make explicit what they are thinking and seeing. Thus, the students in these studies were requested to talk as much as possible whilst using the program. I asked them to provide a running commentary in which they explain what they are doing, seeing and thinking. Students who were reticent to talk were encouraged to do so by the observer (RJD) who asked "prompting" questions.

As the students used the simulation program, their actions, their comments and any comments that the observer made, were recorded on protocol sheets (appendix 3). A hardcopy printout of the information presented on the VDU by the computer or by the student as INPUTs was obtained for future reference.
Following the completion of the program-run, a second interview was carried out. This interview, commenced by asking a number of questions, three of which had been previously asked during the pre-run interview:

a) What do you think the main points that were brought out by the program?

b) Have you been taught these points before?

c) Would you define a "food pyramid"?

d) Imagine that you are a teacher who has to give a series of lessons in ecology. How would you explain a food pyramid to the students?

e) Can you give an example of a food pyramid?

Following these questions students were questioned about their program run. The stimulated recall technique (Calderhead, 1981) was used during the interview to try and obtain more detailed information about what they had observed or thought about at certain times during their program run. For this I made use of the printout of their program run and the observation protocol sheets. This was especially necessary for those students who had failed to provide a detailed running commentary. I felt that in this way, some of the inevitable omissions which all students will make when trying to provide a commentary would be avoided.
The third, and usually brief, part of the interview was concerned with ascertaining how well the student had enjoyed (or otherwise) the program, and any criticisms they might have had or any suggestions for the improvement of the program.

The post-run interview were tape-recorded and transcribed verbatim.

2.5.4 Evaluation of student learning activities.

Having acquired a set of protocol sheets, a hardcopy printout of the program run, and interview transcripts (pre- and post-run interviews) for each student participating in these studies, the problem was how they should be analysed to find out what had been learnt, how and why. A variety of methods were developed, some of which had to progress through a number of developmental stages before a satisfactory method evolved. The analysis of the available data for each of the students attempted to determine:

i. The factual knowledge acquired,

ii. How the student's conceptual structure had changed during the program run, and why,

iii. How the program had been used in terms of a "scientific exercise".
The pre- and post-run interviews provide some idea as to the knowledge that has been acquired using a CAL program. However, little more is achieved here than could have been achieved by using pre- and post-tests. More important and interesting are the ways in which the students acquired concepts, the order in which they might do so, and the factors which influence these processes. These were investigated by a number of methods including the construction of concept maps and by using the Interaction Model.

Concept maps, although they show in outline how concepts are acquired in relation to one another, are not dynamic and show the process of learning demonstrated by the students.

The Interaction Model which I developed as a method of analysis, on the other hand, attempts to show the dynamic nature of the learning experience. The Interaction Model is used in these studies as the main way by which the protocol sheets and interview transcripts are analysed. Each student's learning experience is described using the Interaction Model. This forms part of a set of clinically detailed case-study notes.
The method finally developed for analysing the protocol sheets and interview transcripts consists of the following procedures:

i. Using the information from the pre-run interview to determine the pre-existing beliefs concerned with the concept "food pyramid".

ii. Using the observations of the students, their comments during the program run and from the post-run interview data, I attempt to describe, in detail, verbally and diagrammatically (using the Interaction Model) the process of student learning. The descriptions of learning are chronological, episodic representations of this process. The diagrams thus attempt to show a dynamic learning process.

iii. Using the post-run interview data the net result of the student's program run is described in terms of the factual knowledge acquired.
Chapter 3
Pilot Study Results

3.1 Introduction

The aims of these pilot studies were:

i. To evaluate the effectiveness of CAL as a method of learning when compared to other learning milieu.

ii. To develop and evaluate methods of evaluation for the learning processes demonstrated by students participating in these studies.

In chapter 2, I described the various teaching/learning media used in these pilot studies. In this chapter I will discuss the results of this comparison and the results obtained using other CAL programs and learning milieu. I will also include in this chapter a discussion of the methods I used in these pilot studies to evaluate student learning activities.
3.2 Comparison of the effectiveness of EVOLU and a tutorial

3.2.1 Overview of Methodology

A full account of the methodologies used in these pilot studies was given in section 2.4 of the previous chapter. In this section, I intend only to summarise the methodologies to refresh the reader's memory.

Students from two courses (TEC Certificate and TEC diploma in Science) were used in these pilot studies. Each group of students was divided into matched groups based on past assessments of their course work. One group from each course used the program EVOLU working in pairs at the microcomputer, the other group from each course attended a tutorial session. All student activities at the computers were recorded on protocol sheets (appendix 3). The tutorial session was tape-recorded and transcribed verbatim. The students were interviewed and asked to complete a questionnaire after using EVOLU or taking part in the tutorial. One week following the CAL or tutorial session the students were given identical written assessments (appendix 6) to determine their understanding of the topic, industrial melanism in peppered moths.
3.2.2 Protocol Analysis

3.2.2.1 Method

All activities, that is both of the students and of the supervising teacher, that were observed during the use of EVOLU were recorded on protocol sheets. These protocol sheets (appendix 3) were divided into four columns:- Time, student actions, student comments, and teacher comments.

The student actions noted were mainly the INPUT parameter values, but occasionally they included observations that the students had referred to their package notes or some other similar sort of activity. Student and teacher comments were usually recorded verbatim on the protocol sheets, but occasionally only a summary could be recorded.

The protocol were analysed to determine the cognitive level of all student activities. This analysis was performed using my taxonomy of cognitive activities (figure 2.3).
<table>
<thead>
<tr>
<th>Time</th>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.14</td>
<td>Read package notes.</td>
<td>Devon is country-like and unpolluted. Built-up areas such as London are polluted. Discussed which mutation rate to use, trying to relate this to the number of dark and light moths polluted areas (looking at fig. 2 in the package notes).</td>
</tr>
<tr>
<td>9.18</td>
<td>Commenced program run.</td>
<td>Discussed which mutation rate to use, trying to relate this to the number of dark and light moths polluted areas (looking at fig. 2 in the package notes).</td>
</tr>
<tr>
<td>9.20</td>
<td>Input mutation rate of 7. Input 30,000 light moths. Input 70,000 dark moths.</td>
<td>Discussed the year in which they will change the environment in the simulation.</td>
</tr>
<tr>
<td>9.22</td>
<td>Input year 30.</td>
<td>&quot;Numbers of light and dark moths should stay constant.&quot;</td>
</tr>
<tr>
<td>9.23</td>
<td>Input 1 (environment favours light moths). Looked at output of results.</td>
<td>Decided too many dark moths for a rural area.</td>
</tr>
</tbody>
</table>

Figure 3.1 Extract of an analysed protocol sheet of a pair of students using EVOW
To analyse the protocol sheets, the activities were numbered to show their chronological order. Each activity number was encircled to distinguish it from the cognitive level number I assigned to that activity and shown on these protocol sheets by the side of that activity number. Figure 3.1 illustrates the result of such an analysis. Encircled numbers representing a particular activity, numbers not encircled represent the cognitive level assigned to that activity.

3.2.2.2 Validation of Protocol Analysis

I felt that it was necessary to check my analysis of these student activities and comments. Two judges were chosen both of whom were teachers, had educational qualifications and had used CAL in their teaching. I thus hoped that they would not be too unfamiliar with either this type of CAL output or the educational terms and concepts being used to analyse the data.

Judge 1 (CD) was a part-time biology teacher at Guildford County College of Technology having obtained her post-graduate certificate in education in 1980.

Judge 2 (JHC) had been teaching physics at Guildford County College of Technology for nine years. He had obtained a M.Sc. in physics education. He has had considerable experience in using CAL in his physics teaching at the College.
To enable as good a judgement as possible of the analysis of the observation students, the protocol sheets of a pair of TEC Certificate students using POND-2 were used. I chose POND-2 because I believed that this program had encouraged activities and comments of a wider range of cognitive levels than had EVOLU and would, therefore, be more suitable for this exercise. I had judged that these students had made the following number of activities at each of the twelve cognitive levels in my taxonomy:

<table>
<thead>
<tr>
<th>Cognitive level:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of activities</td>
<td>31</td>
<td>20</td>
<td>8</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
To allow the judges to make their evaluation of the cognitive level of each of the activities of students using a CAL program, I provided them with:

i. A description of the program POND-2, the concepts that the students should encounter and acquire by using the program,

ii. The protocol sheets on which each of the students' activities and comments had been distinguished and numbered (1 to 76), (see appendix 7a).

iii. A hardcopy printout of a run of the program using the students' INPUT values which I obtained from their protocol sheets - a hardcopy printout of the students' actual run is not available),

iv. A description of each of the twelve cognitive levels in my taxonomy of cognitive levels.

I asked the judges to assign a cognitive level to each of the students' activities marked on the protocol sheets. In addition, the judges were asked to say (1) whether they would have distinguished any other student actions or comments which they thought I should have, but didn't, distinguish, or (2) whether I had distinguished a student comment or action which they believed I should not have done.

On the return of the completed protocol sheets by the judges, I determined:-

i. The level of agreement between myself and each of the judges,

and

ii. The level of agreement between each of the two judges.
Both judges had commented to me during the period they were analysing the protocol sheets, and indeed afterwards, when they had returned the sheets, that they thought there could easily be discrepancies in their interpretation. These discrepancies could have occurred because they had not known the full history of the students and thus did not know whether some of the activities were, for example, merely recall of material or had been a hypothesis put forward by the students. Therefore, for each of the activities where my assessment of its cognitive level disagreed with that of a judge, the judge was asked the reason why they had placed assigned that particular cognitive activity to the activity. If I believed their reason to be valid, that is not disagree with my knowledge of the situation that prevailed, I then checked whether the cognitive level to be appropriate for that reason. If not, the judge and myself negotiated the "correct" level. If I believed the reason provided by the judge not to be valid, I then discussed with the judge what I thought had been happening at that point in the students' program run. This I was able to do having been present when the students had used the program, and thus knowing more of what had occurred at that time in the program run. By discussing what we believed to have happened, then either the judge or myself changed our opinion of the level of the activity, or we agreed to disagree. Under no circumstances did I, of course, attempt to impose my judgement on a judge. This negotiating exercise was intended only to provide the background information for judges that they felt they lacked to carry out the analysis.
On occasions the judge would admit that s/he had made an error in their judgement, for example:

"I thought that this was recall of knowledge. Yes, it is a control of the experiment, that is level 7. It is recognising the principle of a given situation. The students have not done anything yet. You are right!" (CD)

"I don't know why I said that this was level 4. It is level 1." (CD)

"Not right here. My mistake. Should be 3." (JHC)

On other occasions, our discussions led to a change of the judges opinion:

"I thought it was observation of what happened. Therefore should be 3. Interpretation." (JHC)

"Misunderstanding of what the student said. Therefore level 6." (JHC)

"I thought that this was prediction, but they are recalling that January is a cold month and therefore there are fewer organisms, that is level 1." (CD)

On other occasions, our discussion did not lead to a change of the judge's opinion:

"I have said that this is control of an experiment. I don't think that it is a strategic decision, it is more than that. I have presumed that the students are talking about the fish. I think that they are analysing using previous information they have obtained about the fish." (CD)

"I don't think it is translation into words. They are killed by the pollution. That is interpretation. Level 3." (JHC)
Figure 3.2 shows the level of agreement between myself and the judges, and between the judges initially and following these discussions.

<table>
<thead>
<tr>
<th></th>
<th>Judge 1</th>
<th>Judge 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJD</td>
<td>41% (93%)</td>
<td>75% (93%)</td>
</tr>
<tr>
<td>Judge 1</td>
<td>47% (92%)</td>
<td></td>
</tr>
</tbody>
</table>

(Note: figures in brackets are after negotiations)

Figure 3.2  Level of agreement between judges in the analysis of POND-2 protocol sheets

The relationship between cognitive level and the level of agreement is shown in figure 3.3. Interestingly, the level of agreement between myself and the two judges appears to decline, perhaps as one would expect, as the activities appear to be of a higher cognitive level.

<table>
<thead>
<tr>
<th>Cognitive level assigned to student activities</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>% agreement with judge 1</td>
<td>58</td>
<td>65</td>
<td>38</td>
<td>50</td>
<td>40</td>
<td>57</td>
<td>20</td>
</tr>
<tr>
<td>% agreement with judge 2</td>
<td>100</td>
<td>90</td>
<td>50</td>
<td>50</td>
<td>20</td>
<td>29</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 3.3  Level of agreement between judges (POND-2 protocol sheets)
A negative correlation of -0.80 was obtained between the cognitive level and the percentage agreement obtained with the two judges (99.9% level of significance). This, together with the rather poor initial level of agreement with the judges convinced me it was necessary to provide a second set of protocol sheets to the judges to be analysed. The experience that the first attempt provided should prove to be beneficial to the judges.

For the second attempt I provided a set of protocol sheets (appendix 7b) of a pair of students using a program, PREY, of predator-prey relationships together with similar additional information that I had provided for the first attempt. This attempt proved to be much more successful in that a higher level of agreement was obtained not only between myself and the judges, but also between the two judges as seen in figure 3.4.

<table>
<thead>
<tr>
<th>Judge 1</th>
<th>Judge 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>RJD</td>
<td>70%</td>
</tr>
<tr>
<td>Judge 1</td>
<td>65%</td>
</tr>
</tbody>
</table>

Figure 3.4 Level of agreement between judges on PREY protocol sheets
The level of agreement at each of the cognitive levels at this second attempt now appears not be significantly correlated to the level of the activity as shown in figure 3.5 where a correlation coefficient of -0.434 was obtained.

<table>
<thead>
<tr>
<th>Cognitive level assigned to student activities</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>% agreement with judge 1</td>
<td>90</td>
<td>73</td>
<td>10</td>
<td>0</td>
<td>60</td>
<td>67</td>
</tr>
<tr>
<td>% agreement with judge 2</td>
<td>80</td>
<td>80</td>
<td>30</td>
<td>25</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

Figure 3.5 Level of agreement between judges analysing PREY protocol sheets

It thus appears that the experience that the judges obtained during their first attempt at assigning cognitive levels to the student activities on the protocol sheets had proved beneficial in two ways. (a) The level of agreement between myself, and (b) The two judges was now at a satisfactory level of approximately 70%, and the tendency for those activities of "higher cognitive level" to prove more difficult to be assigned to a non-disputed level was reduced in its frequency. I thus felt that the way in which I had used the taxonomy of cognitive levels to analyse the protocol sheets to be valid, and liable to little dispute from a person with equivalent experience of using it.
3.2.2.3 Analysis of Student Activities in Tutorials

The transcriptions of the tutorial were analysed in a similar way to the protocol sheets for the CAL groups. The answers to questions posed by the lecturer and other comments made by the students were numbered and assigned a cognitive level according to my taxonomy. The way in which the activities of the students varied during the use of the CAL program and the tutorial is shown in figures 3.6 and 3.7 for the TEC Diploma and Certificate groups respectively.

3.2.3 Results

An "ideal" program run of EVOLU, I believe, should be concerned with observing moth populations in the four different environmental areas (see section 2.4.3), as well as with observing the effect of different mutation rates on the developing populations of moths in an environment. The minimum required of the students, therefore, is the observation of six simulations.
Figure 3.6  
TEC Diploma course - The range of cognitive activities of students in the CAL and Tutorial groups
Figure 3.7  
TBC Certificate course - The range of cognitive activities of students in the CAL and Tutorial groups

- 110 -
Each simulation should involve four main student activities:-

1) Choosing a mutation rate for the evolution of dark moths from light, or vice versa. I have regarded this to be a level 5 activity (that is, recognises the operation of some principle in a given situation).

2) Choosing the numbers of light and dark moths in a particular area (rural or urban, for example). The choice of the frequency of these two forms of moth is regarded as being a level 7 activity (able to identify hypotheses, assumptions, controls of a given experiment) since to determine the proportion of light and dark moths in a population needs the student to realise and understand the effect the environment has on a moth population.

3) Choosing the year during which the environment will change. First of all the student has to decide whether the environment will change, and if so, when. In the package notes various models are suggested, for example, areas that are "newly industrialised" and "becoming smokeless" implying that the changes occur relatively late in the thirty year period that students study. These decisions are taken to be level 3 cognitive activities (interpretation in that data is explained to show cause and effect).

4) Choosing which form of moth, light or dark, the environment will favour if, or when, it changes. This I have taken to be a level 6 activity (predicts the effect of a change of factor on a situation). It requires an understanding of the relationship between camouflage of the moths and predation of the moths by birds to make a prediction.
Thus the basic repeating pattern of activities, for an ideal run, would consist of a level 5 activity followed by a level 7, a level 3 and finally by a level 6 activity.

Figures 3.6 and 3.7 show the range and proportion of activities, at each of the cognitive levels, of two pairs of students using the program EVOLU.

In the students' run the "ideal" pattern of cognitive activities was followed for a considerable part. However, some of the activities were of lower cognitive activity than for the ideal run because teacher help was provided at these times to overcome some of the students' difficulties. The activity, for example, could be one of interpretation (of the help provided) rather than prediction. Additional activities are also demonstrated. For example, where comments are made concerning their understanding of what has happened in the simulation or in the form of a prediction as to what might happen after they have input certain parameter values:

"Environment will change because of industrial development." (level 3 activity - TEC Diploma group).

"Birds will eventually get the dark moths when there is a change in the environment." (level 3 activity - TEC Diploma group).

The main objective for the tutorial was to provide the students with an understanding of evolutionary processes as illustrated by industrial melanism of peppered moths. The students had not previously encountered this concept of industrial melanism in their present courses. Consequently it was necessary during the tutorial to provide the students with the necessary facts about this topic. However, the
students were involved with the tutorial in that they were asked questions which they (the group) had to answer. These questions were normally answered as briefly as possible by the students. The students did not normally enter into or initiate discussions concerning any topic which might have been of interest to them. To some extent this reluctance to participate surprised me. As groups, and usually as individuals, they were not prone to restrict what they said in the classroom by feelings of embarrassment. I also felt that they normally had a reasonably good rapport with the lecturer in charge of the tutorial.

Some indication as to this reluctance to participate is given by Perry (1970). Most teachers see the tutorial as a means for students to develop initiative and scope in their thinking. However, as soon as a student makes a mistake or is not as exact as the tutor wishes, the tutor feels compelled to correct the statement made by the student. According to Perry, it only requires three to five of these corrections to defeat the "student's initiative for search and the flow of their exploration". The teacher, because of the students' reluctance to participate "finds himself in a monologue". This correction of the students' mistakes and inexactitudes certainly occurred quite frequently in the tutorial observed during these pilot studies.
As a result of this apparent reluctance to participate, most of the students' activities during the tutorial appeared to be of a low cognitive level, usually merely providing an indication that they had acquired certain factual knowledge. How important a factor the teacher's corrections were in reducing the amount that the students talked and showed relatively high cognitive activities is a matter for speculation. At the time I was not interested why the students demonstrated relatively lower cognitive activities than the students who had used EVOU. I was merely interested in detecting a difference. Of the two groups, the TEC Certificate students were more willing to participate in the tutorial.

This willingness on the part of the TEC Certificate students to participate in the tutorial is exemplified by the fact that they questioned the lecturer during the tutorial, which the TEC Diploma group did not do at all during their tutorial. This would account for some of the activities being of a higher cognitive level for the Certificate group.
Figure 3.8  The range of cognitive level of student activities in tutorials and using EVOLU
Figure 3.8 shows that, overall, EVOLU had encouraged a more even spread of cognitive activities than had the tutorial. The majority of the activities of students using EVOLU were grouped around levels 3 to 7, whereas for students participating in the tutorial, the majority of the activities were grouped in levels 1 to 3.

By choosing a tutorial as a learning situation as a comparison for the effectiveness of a CAL program I had hoped that the students would be more active than perhaps they would be, say, in a lecture or watching a film. I had hoped that the tutorial would make less use of a didactic approach. The higher cognitive levels that the students using CAL demonstrated, were activities such as experimentation and reasoning. These activities might have resulted in the students becoming more interested in the topic that they were involved with, and thus more motivated to learn about the topic.

So that the effect of CAL on the retention and understanding of the body of knowledge presented by EVOLU could be compared with the effectiveness of the tutorial, all of the students participating in these pilot studies were given a short-answer achievement test (appendix 6) concerned with evolution, in particular, industrial melanism. In this test, questions 1 to 5 were assessing their knowledge of the subject, questions 6 to 9 their comprehension of the subject. Figure 3.9 shows the results obtained in this test by both groups of students attending both of the courses.
### Knowledge questions (5 marks)

<table>
<thead>
<tr>
<th></th>
<th>Knowledge questions</th>
<th>Comprehension questions</th>
<th>Total marks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEC Diploma</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(CAL group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NK</td>
<td>4.0</td>
<td>3.5</td>
<td>7.5</td>
</tr>
<tr>
<td>SM</td>
<td>5.0</td>
<td>4.5</td>
<td>9.5</td>
</tr>
<tr>
<td>KP</td>
<td>5.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>CW</td>
<td>4.5</td>
<td>3.5</td>
<td>8.0</td>
</tr>
<tr>
<td>(Tutorial group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KF</td>
<td>5.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>SL</td>
<td>4.0</td>
<td>4.5</td>
<td>8.5</td>
</tr>
<tr>
<td>AM</td>
<td>4.0</td>
<td>3.5</td>
<td>7.5</td>
</tr>
<tr>
<td>NM</td>
<td>4.0</td>
<td>4.5</td>
<td>8.5</td>
</tr>
<tr>
<td><strong>TEC Certificate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(CAL group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>5.0</td>
<td>4.0</td>
<td>9.0</td>
</tr>
<tr>
<td>KG</td>
<td>3.5</td>
<td>4.5</td>
<td>8.0</td>
</tr>
<tr>
<td>RP</td>
<td>5.0</td>
<td>5.0</td>
<td>10.0</td>
</tr>
<tr>
<td>(Tutorial group)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KB</td>
<td>3.0</td>
<td>4.0</td>
<td>7.0</td>
</tr>
<tr>
<td>TT</td>
<td>3.5</td>
<td>3.5</td>
<td>7.0</td>
</tr>
<tr>
<td>SS</td>
<td>2.5</td>
<td>3.5</td>
<td>6.0</td>
</tr>
<tr>
<td>SW</td>
<td>4.0</td>
<td>4.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

**Figure 3.9** Results of Industrial Melanism Test

The marks of the CAL and tutorial groups in both courses, separately and combined, were compared using the Student's t-test, the results of which are shown in figure 3.10.
<table>
<thead>
<tr>
<th>TEC Diploma comparison of CAL and Tutorials</th>
<th>t-value</th>
<th>level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge qu's</td>
<td>1.083</td>
<td>N.S.</td>
</tr>
<tr>
<td>Comprehension qu's</td>
<td>0.739</td>
<td>N.S.</td>
</tr>
<tr>
<td>All questions</td>
<td>0.225</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEC Certificate comparison of CAL and Tutorials</th>
<th>t-value</th>
<th>level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge qu's</td>
<td>2.206</td>
<td>90%</td>
</tr>
<tr>
<td>Comprehension qu's</td>
<td>2.535</td>
<td>95%</td>
</tr>
<tr>
<td>All questions</td>
<td>2.927</td>
<td>&gt;95%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TEC Diploma + Certificate comparison of CAL and Tutorials</th>
<th>t-value</th>
<th>level of significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge qu's</td>
<td>2.295</td>
<td>&gt;95%</td>
</tr>
<tr>
<td>Comprehension qu's</td>
<td>0.815</td>
<td>N.S.</td>
</tr>
<tr>
<td>All questions</td>
<td>2.073</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>

(Note: N.S. = "Not significant at 90% level")

Figure 3.10 Student's t-analysis of Assessments
There is some indication from these results that CAL has enabled the students to perform better than they would otherwise have done if the same material had been presented in the form of a tutorial. This apparent educational gain of using a CAL system instead of a more traditional teaching or learning method has been reported elsewhere (Ayscough [1973], Harding [1976], and the Open University by Ayscough [1980]).

Why should this be? It could be that being active and being involved in finding out "what happens when..." might have resulted in the students becoming more interested in the topic and thus become more motivated to learn (Crovello [1974]). There is some evidence in my results to support this hypothesis. In their replies supplied on the questionnaires:

i. not one member of both CAL groups said that they had not enjoyed the experience, whereas some members of the tutorial groups tended had not enjoyed their tutorial as seen in figure 3.11. The question "had you enjoyed the learning experience" was asked, and replies were given according to a five-point scale, the poles of which were "very much" (1) and "not at all" (5).
ii. Every member of both CAL groups believed that "this mode of learning was better than a normal laboratory practical or tutorial". Comments such as those given below were made by the students on their questionnaires:

"More interesting. You feel responsible and feel as though you are controlling the program." (SM)

"It added a new dimension to lab. work, i.e. you could control how the experiment worked." (KP)
"You were able to understand mutation far more easily than if it was just taught to you." (KP)

On the other hand, five of the eight students who participated in the tutorial believed that the tutorial could have been improved in some way:

"Could have shown more diagrams and given us more examples." (AM)

"More use of Audio-Visual Aids." (TW)

"Do some practicals and field work." (KB)

However, since these have been the only results that I have obtained which make a direct comparison of the effectiveness of CAL and alternative methods of student learning, I feel that I should not attempt to draw too many conclusions from the data.

It does seem, however, that the use of a CAL program can result in a different range of cognitive activities being demonstrated by the students than would have been demonstrated in alternative milieu.

Ayscough (1976b) believes that CAL can be used, as an alternative to laboratory experimental work, to develop the higher cognitive skills of decision-making and problem-solving. The results of these pilot studies also indicate a higher level of cognitive activity than occurs with alternative methods of teaching/learning.
The question could be asked whether CAL programs generate a similar range of high level cognitive activities. Kemmis (1977a) has provided qualitative evidence concerning the difference in pedagogic potential of CAL programs.

The next section of this chapter describes a comparative analysis of the cognitive activities generated by a range of different biology CAL simulations. Here I wanted to see whether one can expect different programs to have different cognitive potentials.

3.3 A Comparison of the Learning Activities generated by different CAL Programs

3.3.1 The CAL Programs

A number of different types of program were used for the comparison of pedagogic potential of the different CAL programs. These programs are listed below, together with a brief description of the nature of the program.

i. POND-2. This program will be described in 4.2.1 in some detail as it forms the basis for the POND series of programs used in the main studies.

ii. PREY. This, like POND-2 is a Schools Council "Computers in the Curriculum" program. The author of the package notes describes (Denham [1978]) the aim of this program as being
"to investigate a simple model of the interaction between one predator and one prey species. No particular species are bien modelled...". The students are instructed to investigate the effects of different initial numbers of predators and prey on the subsequent population sizes.

iii. GROWTH CURVE. This is a program that I wrote to enable students to become more familiar with the effect of the generation time on the growth rate of a bacterium, and the effect of inoculum size on the growth curves subsequently produced. The output of data by the program can either be in graphical or tabular formats.

iv. GROWTH CURVE 2. This is the second of a series of programs that I have written concerned with growth kinetics. It allows the students to determine and observe the effect of varying parameter values on the growth of the organisms. The output from this program can either be as a graph showing the growth curve obtained, or as a table showing the numbers of the cells at time intervals specified by the student following the inoculation of a batch culture of bacterial cells.

v. GROWTH CURVE 3. This, the third of my series of GROWTH programs, enables students to determine the effect (that is the minimum, optimum and maximum values) of a range of parameters on the growth of a range of micro-organisms. Six organisms are available in the simulation, all of which have different growth requirements. In addition to observing the effect of various parameters on growth, the program requires the students to develop methods of experimentation. Without adequate methods of experimentation being developed to meet
the challenge of a simulation model that requires all the parameters to fall within the "biokinetic zone" for the chosen micro-organism, no growth, and thus no data, will be obtained.

vi. COEXIST. This program was developed at Chelsea College and is published by Edward Arnold (Murphy [1975]). In this program the students can, according to the author of the package notes (Murphy [1975]), "carry out 'experiments' to investigate the effect of changing certain parameters which have a bearing on the growth rates of non-competing ... and competing species." The output of data by the program is only in graphical format.

3.3.2 Methodology

The students were normally provided with package notes for the program that they were using to introduce the material being presented by the simulation. They used the program working in groups of two. Each pair of students were observed using the program, their actions and comments being written on the protocol sheets in an identical manner to that previously performed for EVOJ. These protocol sheets were analysed using my taxonomy of cognitive levels as previously described. Questionnaires were also completed and analysed.
Table 3.12 shows the range of cognitive activities and their frequency encouraged by the programs used in these pilot studies.

Figure 3.12 The range and proportion of cognitive activities at each cognitive level
Figure 3.13a  Growth Curve 2 - Comparison of Activities of two pairs of students

Figure 3.13b  POND-2 - Comparison of Activities of two pairs of students
Figures 3.13a and 3.14b show how the use of the same program by different pairs of students will usually result in a different range and proportion of cognitive activities being demonstrated.

3.3.4 Conclusions

When individual pairs of students using CAL programs are compared, it is perhaps not surprising to find that:

there appears to be a difference in the way that they use the programs and the cognitive activities that they demonstrate. Some students appear to use a program in a rather superficial way; other students appear to use the programs in a more thoughtful and reasoned manner.

This difference in learning behaviour might be similar to the differences in learning approach described by Marton (1976). This difference in approach to using CAL programs is investigated further in chapter 10.

The considerable differences in cognitive activities may merely represent differences in student behaviour, but may also, of course, represent the effect that CAL programs may exert on student behaviour.

If the histograms in Figure 3.13a and 3.13b are compared, it can be seen that although pairs of students using the identical program demonstrate differences in level of cognitive activity,

there are also marked differences in the proportion of activities at each of the cognitive levels for the different programs.

It would thus seem that this method of analysis that I have used in these pilot studies has detected an effect that the structure of a CAL
program can exert on student cognitive activities.

3.4 A Comparison of a CAL program and a Laboratory Exercise

3.4.1 Introduction

The TEC Diploma students that participated in the earlier part of these pilot studies had to study the basic principles of experimental design as part of their course. As an introduction the students were asked to design the necessary equipment and perform an experiment that would determine the effect of the length of a pendulum and the weight of a pendulum bob on the period of the pendulum.

3.4.2 Methodology

The students were provided with a short length and a long length of string, a plastic bag, a beaker of sand, a clamp and a stand. They were informed that they could ask for any more equipment that they thought they required. The students worked singly, but conversations between the students and with the teacher were allowed. Two students were observed closely during the practical exercise, the observations made of these students were recorded on protocol sheets as previously described. All students, at the finish of the lesson, completed a feedback questionnaire (appendix 5).

Four weeks after the laboratory exercise, two of the TEC Diploma students used a simulation, PENDULUM, to determine the effect that the
length of the pendulum and the bob weight have on the period of a pendulum. The students used the simulation program together. Protocol sheets of their use of the program and feedback questionnaires were completed as in the previous exercises.

One student was interviewed about their experience of the laboratory exercise; the pair of students using PENDULUM were also interviewed about their experience of the program and how it compared with the laboratory exercise. These interviews were tape-recorded and transcribed verbatim.

The three sets of protocol sheets were analysed as in the previous exercises according to my taxonomy of cognitive activities.

3.4.3 Results

3.4.3.1 Design of Pendulum Apparatus and Performance of Experiments

The following are my account, in brief, of the laboratory work of those students that I had observed.

3.4.3.1.1 Stewart's Experiment

Stewart (SM), after recalling what a pendulum looked like, assembled one using the apparatus available to him. Some thought as to how to discover the relationship between (i) pendulum length and the pendulum's period, and (ii) the bob weight and the pendulum's period, must have occurred because he prepared a table in which he could write
any results that he obtained. Initially, the pendulum swung in all
directions because of an uneven distribution of sand in the plastic
bag. He remedied this by folding the plastic bag to form a small,
compact bob. The next problem was how to determine exactly one
oscillation of the pendulum and thus its period. He solved this by
placing a folder at the extremities of the swing of his pendulum.
Other similar problems in the design of his pendulum were encountered
and overcome.

On proceeding to the experimental part of the exercise, it appeared
that Stewart was uncertain as to the details of the experiment he
should perform. The first indication I had of this was when he
recorded his results in a notebook rather than in his previously
prepared table. In his feedback questionnaire, he said the session
could have been improved:

"If you made it more clear what we were meant to be doing."

The uncertainty of what was required had resulted in a change of his
experimental aims. In the interview following the exercise, it
transpired that initially he was going to keep the length of the string
constant, but then he decided to keep the weight of the bob constant
because:

"The time it would take to weigh out different amounts of sand,
unless you had different amounts of sand in, which you could just
change, you wouldn't have time to get a list of results in the
time available."
During his experiments Stewart became aware that the results that he was obtaining were liable to error. After some thought and then discussion with a colleague working on the same bench, he realised that he should time more than one oscillation to obtain a more accurate value of the period of one oscillation. Having apparently now designed the experiment to his satisfaction, he now obtained readings for five different pendulum lengths.

Figure 3.14 shows the range and proportion of Stewart's activities at each of the levels in my taxonomy.

3.4.3.1.2 Nariman's Experiment

Nariman (NM) tried initially to imitate an experiment she had previously seen performed. On that previous occasion the pendulum bob had been a ball-bearing with its centre of gravity, of course, in the centre of the sphere. Working with a plastic bag filled with sand proved to be a difficult transformation of experiences for her. She could not see how to find the centre of gravity of her bob. This disturbed her. She looked at Stewart (SM) fold his bag, and she folded her bag in the same way. However, not being able to copy exactly what she had seen on the previous occasion affected her performance throughout the rest of the exercise. It was only by looking at Stewart folding his bag, and then copying him that she was able to set up her pendulum. With this problem apparently resolved, her progress in obtaining results was reasonably good in comparison with the rest of the class. However, she did encounter one other problem which she could not resolve by herself and she had to be helped
by the teacher. It would seem, therefore, that Nariman was not capable of solving problems in such a situation as easily as one would expect and wish of this type of student.

Nariman's range and proportion of cognitive activities at each level in my taxonomy are shown in Figure 3.15.

3.4.3.1.3 Comments on the Pendulum Experiment

It would have been of some advantage to me to have the students working in groups of two to allow a conversation to take place more freely and thus allow a greater insight into the learning and problem-solving processes taking place during this laboratory exercise. Even with this disadvantage it was possible, from their actions and from their short conversations, to see some of the processes that were taking place.

From Figures 3.14 and 3.15 it can be seen that the main cognitive activities taking place were those of problem-solving and experimentation. Some students appear, not unnaturally, to be better at one or another of these activities. Nariman, for example, did not appear to be a very capable problem-solver.
3.4.3.2 Use of PENDULUM

Having previously performed the pendulum laboratory exercise would have helped Cliff (CW) and Nilesh (NK) use this computer simulation of a pendulum. This was obvious from the first comments that they made:

"I think we will vary length, weight doesn't vary it much."

Their decisions concerning the design of the experiment were made based upon their experience with this laboratory experiment. Even when reading their results they realised their approximate accuracy. As they progressed, they repeated some of their earlier runs because:

"It was the first one we did so we may have got more accurate."

Figure 3.16 shows their range and proportion of activities at each level of my taxonomy.
Figure 3.14  Range and proportion of cognitive activities in pendulum experiment (SM)

Figure 3.15  Range and proportion of cognitive activities in pendulum experiment (NM)

Figure 3.16  Range and proportion of cognitive activities in pendulum experiment (CW & NK)
3.4.4 Comments on the Comparison of a Simulation and a Laboratory Exercise

When asked, Cliff and Nilesh thought that they had got more from using the program PENDULUM than from using the apparatus that they had designed, they replied:

"It's a lot quicker. I don't think you get any more. I got similar results from doing it on the bench."

And then:

"You could learn more things because you have more time to play with the program."

"The program does replace the experiment quite nicely, but you don't learn experimental techniques. The advantage seems to be that you can do a lot more with it in a lot shorter time. If you are doing the experiment physically you are lucky to get ten results in an hour because you have got to keep weighing out and setting up, changing lengths of string. The computer does that in seconds. But there again you cannot have experimental error which would change the results...If I wanted to practice experimental technique I would use the experiment."

These comments by the students would appear to summarise many of the different roles for computer simulations and laboratory exercises. That is, computer simulations provide rapid results and thus can produce a larger number of results about a wider variety of the aspects of the simulation model. On the other hand, the laboratory exercise does allow students to practice their experimental (that is practical) techniques.
3.5 Implications for the Main Studies

These pilot studies have several important implications for the main studies, the most important of which are concerned with the analysis of the effect of a CAL program on the various cognitive activities of the students using the programs.

In these pilot studies I attempted to describe each of the cognitive activities according to my taxonomy. Each level of the taxonomy represents a different activity such as interpretation, prediction, the formulation of a hypothesis, and so on. These are very similar, although constituting a more detailed classification, than those cognitive activities described by Kemmis' typology and Laurillard's "types of learning". These mostly describe the result of the influence that the structure of the CAL program has on student activities.

At the end of the analysis little is known of how the structure actually affects student activities. A comparison of programs shows that a different range of and proportion of cognitive activities are demonstrated by the students using both the same and different programs.

This in itself is an indication that program structure does have an effect on student activities, but it does not show how it produces its effect. More needs to be known of the dynamics of the Student-CAL interaction. The comparison of activities encouraged by the different CAL programs and those generated by other learning milieu show that there are differences in the learning approach adopted by individuals.
In addition to the effect that CAL program structure has on learning, factors such as the individual's existing body of knowledge and their individual style and approach to learning, which influence learning should be recognised in an analysis of learning. By appreciating all of the interfering factors, the creation of a model of computer assisted learning which includes all of the important factors involved with the student-CAL interaction should be possible. As a result of being able to at least partially predict the effect that program structure has on learning, more effective programs in terms of student learning should be possible.

These interfering factors need to be studied not only in the context of CAL, but also more generally for a better understanding of how students acquire scientific knowledge and scientific problem-solving skills. The CAL science simulation program is concerned with promoting an understanding of a particular "package of knowledge", of a certain area of conceptual relationships. How this understanding is acquired will differ from person to person. However, since the programs being used in these studies are concerned with various areas of science, in the context of science "lessons", then one might expect that problems of understanding might be tackled by the students using "scientific methods".
Chapter 4

The Development of the Main Study CAL Programs

4.1 Introduction

4.1.1 The Construction of Models

A large part, if not all, of scientific work consists of formalisation and model-building. It is through experimentation and observation that the scientist attempts to construct abstract representations and laws that formalise "verified" hypotheses concerning real-world phenomena. Such models allow extrapolation, analysis and design, it also allows analysis to learn how the real system can be manipulated for man's own purposes (Spriet and Vansteenkiste, 1982).
Science CAL programs use models in an attempt to encourage students to acquire and become familiar with scientists' models of the real-world. Such programs are said to be simulations of the real-world. A simulation has been defined as:

"The act of running a program which represents an abstract model in order to study the real system's behaviour"  
(Spriet and Vansteenkiste, 1982, page 4)

Simulations can improve complex thinking, avoid encouraging unidirectional thinking and encourage students to consider several aspects of a model at the same time (Wederkind [1977]).

The model used by a simulation program is produced by condensing the necessary amount of information from the modeller's environment. However, this can result in the model being a somewhat poor image of the real-world object. Models encode knowledge. They are often seen as having a marked ability to integrate sets of disconnected relationships and thus facilitate the drawing of otherwise difficult implications.

Real-world processes can be represented mathematically at any required level (Spriet and Vansteenkiste, 1982). If one describes a system at the behaviour level, the lowest of the levels, the model is viewed as a black box. Measurements are made on it in their chronological order.

CAL simulations typically use "black box" types of model. Normally in a CAL simulation some variables of the model are considered as INPUT, that is not under control of the box itself, and others as OUTPUT, that is externally perceivable to the experimenter or to the environment outside the system boundary represented by the box. Experimentation on the real-world process addresses the behaviour level.
The state structure level is said to be where the mechanism for the internal working of the model is described. The highest level is the composite structure level where a system is described by specifying how to construct it by connecting together more elementary black boxes known as components.

Gilbert and Osborne (1980) recognise five types of model:

1) Scale (or iconic) models.

2) Analogue models which reproduce the structure or web of relationships in the real-world system in an abstract way.

3) Mathematical models where the model is summarised or represented by a mathematical equation.

4) Theoretical models which involve the production of a physical representation of a phenomenon which can be applied to the study of the phenomenon without making theoretical assumptions about it. These theoretical models are communicated as verbal or diagrammatic forms.

5) "Archetype" models which are the most abstract of all the models. These are seen as a "systematic repertoire of ideas by means of which a given thinker describes, by analogical extension, some domain to which these ideas do not immediately and literally apply". (Black, 1962).
<table>
<thead>
<tr>
<th>Level of Detail</th>
<th>Type of Model</th>
<th>Form of CAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Spriet &amp; Vansteenkiste, 1982)</td>
<td>(Gilbert &amp; Osborne, 1980)</td>
<td></td>
</tr>
<tr>
<td>Behaviour Level.</td>
<td>Scale Models.</td>
<td>&quot;Black Box&quot; simulation</td>
</tr>
<tr>
<td></td>
<td>Theoretical Models.</td>
<td>programs.</td>
</tr>
<tr>
<td></td>
<td>Archetype Models.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulation Programs.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOGO programs.</td>
</tr>
<tr>
<td>Composite Structure Level.</td>
<td>Analogue Models.</td>
<td>LOGO programs.</td>
</tr>
</tbody>
</table>

Figure 4.1  
Ascription of Types of Model and Forms of CAL to Spriet & Vansteenkiste's (1982) Description of Levels of Detail

It is of course necessary to determine the validity of a model before it is used by students. As one progresses from the behavioural level to the composite structure level it becomes more difficult to determine a model's validity. Nevertheless the claims for the model are
strengthened as validity is shown at the higher levels. Spriet and Vansteenkiste (1982) believe that validation should consider three areas:

i) Validation in deduction - that is its premises are exact or the consequences of the premises are correct.

ii) Validation in induction - that is whether observational data of the real-world and simulation systems are equal.

iii) Validation in purpose - that is whether the goal of the model can be obtained.

The "POND" programs used in my main study are simulations of a pond ecosystem. Models chosen for use in CAL programs are usually a compromise between a model which allows a quantitative understanding of the system, and a model which provides a realistic representation of the system (Wood, 1979). Models, therefore, have often be seen as occupying an intermediate position between observed reality and theory.

Models of environmental systems have been produced on computers since the 1970's. It is now recognised that a precise mathematical description of this type of system is difficult to produce. In many cases, ecosystems are only sufficiently well understood for scientists to be able to provide verbal descriptions rather than precise mathematical ones. Such systems are known as "soft" systems.

The intermediate position taken by models is apparent in both the "inductive" and "hypothetico-deductive" views of scientific reasoning (Gilbert and Osborne, 1980). On the inductive scheme, models provide a vital ingredient in unifying facts towards the formulation of theory.
On the hypothetico-deductive scheme, theory is applied through the model. The construction of models of environmental systems involves considerably more recourse to inductive inference than do models arising say in aerospace engineering and chemical process control. On the other hand, the basic equations characterising dynamic phenomena in environmental systems are far better known than in relatively "darker" areas of biology.

The aim of science simulations, it can be said, is to develop a student's mental model of a phenomenon. Students should be able to "put numbers to their 'feeling for' the system and be able to describe some of the features in mathematical terms, as the underlying program does" (Wood, 1979).

This is a communication problem in that it requires the transfer of a mental picture via iconic, verbal, diagrammatic and symbolic (mathematical) representations, and, by confronting students with contrived situations (for example, experiments), which focus on aspects of reality.

The educational value of a CAL simulation program depends on the ability of a student to learn from his manipulation of a model within the program (Ayscough [1976a]). An important part of science education should be concerned with developing reasoning abilities required for model building and model evaluation. Students should be encouraged to develop an insight into various aspects of scientific method. Wood (1979) recommends that this insight should be brought about by the use of "windows" into the "black box" of the model used by the CAL program.
It is important that students become aware of the various assumptions and simplifications made by the program developer or teacher. By having windows in the black box type of simulation model as Wood (1979) suggests, the level of detail is raised from the behaviour Level to the State Structure Level.

Wederkind (1977) believes that if students work interactively with models of dynamic systems, they should have the opportunity to work with models on different levels of complexity. By working with models of different complexity, the nature of the learning changes. Wederkind describes such changes in learning as:

i. the acquisition of information about the characteristics of the model,

ii. systematisation, or the performance and evaluation of a set of experiments related to a special problem,

iii. problem-solving, students may find their own new problems, build new models and test these models.

This latter stage will probably require the ability of the student to be able to program, and thus the interest that is taken by many people in the relatively simple "structured programming languages" such as LOGO, PASCAL and COMAL.
4.1.2 The Design of CAL Programs

CAL programs are usually bought together with supporting notes and instructions, known as a CAL package. Some people (for example, Lewis [1978]), although believing the computer program to be an essential element of a CAL package, do not believe that it can stand on its own "any more than laboratory apparatus alone can provide a learning experience for students". In the CUSC project, support for the program was provided for example by written material, films, and experiments. Such additional material hopefully leads to the informed use of the program which itself usually provides a means for enriching understanding.

With modern computer technology which is able to provide both written and graphical information on a visual display unit (VDU), there must be a decreasing demand for packages from the students' point of view. The information presented in package notes provides nothing that cannot be provided by the computer. Indeed, by presenting such information on the VDU the students will be more likely to read it than if it were presented separately.

Teachers will still need to refer to package notes, rather than the program, to find out its potential uses. The place of additional exercises such as laboratory experiments will, of course, still have the same important role to play. The place of film material etc. will be in less demand with the recent introduction of interactive videodisc systems and the improvement of computer graphics so that rapid photographic quality displays are possible.
Package notes do not seem to be the most efficient way for students to be "primed" how to use the program. Programs should be designed to be self-supporting. Many at the present time are not, and some indeed are almost impossible to use without additional package notes.

Older students (for example, those in Higher Education) could possibly be relied upon to read package notes, but younger students, for example in schools probably often neglect to do so. Programs should thus be designed to include enough information for any student to be able to use that program and to use it in such a way that the learning experience is a fruitful one. Programs should thus have the "power" to encourage understanding and learning.

Lewis (1978) states that:

"teachers believe that the use of the package will increase the chance of achieving the objectives".

However, the design of the program and the learning goals of the program user will both play an important part in determining whether these objectives are met. My main objective in these studies was to be able to say how the design of the program and the information contained within that program affected learning behaviour and the understanding of concepts.
The use of the computer for CAL in science education has often been referred to as using the "computer as a laboratory". The students can make decisions about what they want to investigate, obviously within the limitations of the program, and how they will perform these investigations. They are not compelled to follow a laid-down procedure. They can ask of themselves "what will happen if....?".

The extent to which this freedom of the student to investigate a problem or series of problems can be extended depends very much on the simulation model used by the program. Some programs use a rather simplistic model, a model from which many of the complex and inappropriate issues and concepts are removed. This only leaves those concepts which are appropriate to the immediate needs of a particular group of students. As Lewis (1978) states:

"There are some inherent dangers here. First, the student may confuse the model system with reality, and secondly the student's investigations may become adversely restrained or directed."

Such problems can be overcome. The first problem can be removed by being honest with the student as to the limitations of the program, and also by relating the model to the real world. The second problem can be overcome by a careful design of the package as a whole.

Lewis cites the "problem guided" strategy as that which approximates the scientific method most closely. With this approach a series of carefully structured questions and problems are presented to the student by the package notes. The use of the computer model in the CAL program is thus only part of the entire process. Lewis sees the structure of CAL programs having a similar basic structure:
In designing the model which will form the PROCESS part of the program (the "machinery" of the program will not be seen [that is it will be a "black box"], but controlled to some extent by the student using the program) the INPUTs to be made by the student must be carefully considered. In the INPUT section, Lewis believes that the student must be carefully guided to provide parameter values which will be used during the PROCESS part of the program. A decision must be made at the time of writing the program as to how much guidance will be provided and the form that this guidance will take.

The danger in providing too much guidance, for example by providing detailed explanatory notes concerning each INPUT value together with ensuring that the values are within a specified range (either by programming "default" values or by recommending a range of values), is that it might inhibit much of the student's desire to experiment with that model. The student will be less likely to find out "what happens if...?" but to merely follow the program through a number of defined situations and observe what happens.

There is also a danger in providing too little guidance, this can result in much time being wasted by the student using INPUT values which will prove to be fruitless in terms of the results provided by the program at the OUTPUT stage of the program. It could easily lead to a feeling of boredom and/or frustration. It may thus be compared with the laboratory experiment that doesn't work.
Feelings such as these just cited will, of course, do little to increase the student's understanding of the simulation model, nor indeed for the student's feelings towards CAL itself as a means of learning. There is already considerable antagonism towards CAL by teachers who had experience of "teaching machines". It would seem unnecessary to have poorly designed CAL programs encouraging similar feelings.

The OUTPUT section of the program must be carefully designed. The student must be able to perceive the correct information, that is the information that the program designers wish to convey to the student. Much has been said of the advantages of using modern computer graphics technology, for example:

"It has become a cliché to say that one picture is worth a thousand words, but only because it is true. A more relevant point is that a few graphs can be worth a great many numbers, to so marked a degree that there are even dangers in saying that a diagram is worth a thousand numbers....People generally have great difficulty in digesting sequences of numbers and understanding the relationships that they contain." (Shirley, 1978)

This quotation continues:

"Much of the subject matter for science students consists of a set of interlocking laws describing functional relationships between observable and derived quantities, and the application of those laws. For most people, such relationships are more easily understood in graphical than analytical form, so if one is to teach for understanding the most natural medium is interactive graphics."

At the time that this was written, microcomputers were beginning to make their "mark" on the computing world. Although these microcomputers usually had some form of graphics available there usually was no way to produce a cheap hard-copy of the graphical information displayed on the VDU. Since that time, dot-matrix printers have become available for microcomputers, the quality of the
hard-copy print improving from low-resolution graphics to being able to print high-resolution graphics. Consequently, not only is a graphical display available for output on to the VDU, but also a permanent record of that information can be retained for later use by the student without having to resort to the expensive Polaroid camera.

The quality of graphical displays in CAL programs can vary from "crude", low resolution diagrams or graphs in monochrome to extremely high quality "photographic" images being displayed on the VDU or printed in colour. The quality of the graphical display must have a marked effect on the perception of the information by the students, and thus its potential in CAL to promote understanding.

Lewis (1978) in describing ways by which the educational benefit of packages can be maximised said that the programs must be capable of being used in a variety of institutions over a number of years. This meant that a package must be flexible to be able to be adapted to changing curricula. Lewis thus expects the programs to be "neutral with respect to educational philosophy". He sees the program as essentially being the model together with an interface with the student. The educational philosophy is provided by the package notes. Lewis's major concern is in ease of transferability rather than to be able to produce a program that will maximise the educational benefit gained by students using that program.
Much can thus be done to ensure that the learning experience is a rich one for those students using CAL programs, for example by:

i. Program guidance to the student can be provided, perhaps merely by suggesting experiments, INPUT values etc., perhaps by modelling a student's use of the program and comparing with an "expert's" use of that program and providing assistance as would appear to be necessary, as has been used for example in Artificial Intelligence systems such as the program WUMPUS (Goldstein, 1979).

ii. Have simulation programs which have windows in the black box, as suggested by Wood (1979).

iii. By providing more incentive to students by making the explicit goals of the program more attractive perhaps by producing game versions of the simulation.

4.2 The Development of the Main Study Programs

4.2.1 POND-2

The package notes for POND-2 (Tranter and Leveridge, 1978) describe the conceptual aims of the program to be:

(a) a realisation that communities of organisms within an ecosystem are in a delicate state, easily upset by natural changes within an ecosystem or by external pressures imposed as a result of man's activities.
(b) a realisation that a community of organisms consists of many populations of individual species which exists together and are interdependent, and that the nature of the community and the size of each population are the direct result of the various inter-relationships existing between the plants and animals within the community.

(c) a realisation that the interdependence of the organisms is reflected by their feeding habits, and that these can be expressed in various ways, including food chains, food webs and pyramids of numbers and energy, and that all communities and ecosystems are ultimately dependent for their existence on solar energy and primary producers.

(d) a realisation that cyclical changes will occur in a community of organisms, even when it is in a "stable" condition.

(e) a realisation that the study of complex situations can be approached by the use of simplified models to establish basic principles.

The authors of the package notes recommend that the students have recent contact with real organisms before using the simulation so that the program is not too abstract a study.

A full listing of the POND-2 is given in appendix 8a. A description of the pedagogic aims of POND-2 are given in appendix 8b.

The program provided by the publishers produced three separate graphs (one each for the fish, herbivore and phytoplankton populations) output to a teletype printer. However, for the small VDU of a personal microcomputer such as the Commodore PET, three separate graphs cannot be presented simultaneously. The graphical display was thus
redesigned to allow the overlay of all three lines representing the behaviour of the three trophic levels. This necessitated using three separate "y-axis" scales, one for each of the populations. The three lines were represented by the initial letters of the three trophic levels, that is F(ish), H(erbivores) and P(hytoplankton). The size of each of these population was represented on the graph each month. The resulting display (see figure 4.2) was an extremely low-resolution form which needed some practice in interpretation. An alternative tabular display was also available to the students (see figure 4.3).
Figure 4.2  Photograph of low resolution graph on PET VDU

Figure 4.3  Photograph of Table on PET VDU
4.2.2 PONDQU

PONDQU is based on the program POND-2. The only difference between POND-2 and this program is that PONDQU contains a number of questions and statements which were designed to be thought-directing. The intention of these questions and statements was to guide the student and to concentrate the student's mind on the concepts which the program is attempting to demonstrate to the student. These questions and "thought-directing" statements (appendix 9) are provided by the program following the use of each of the four modes.

A full program listing of PONDQU is given in appendix 10a, and a full description of the pedagogic aims of the program in appendix 10b.

4.2.3 PONDSGAME

The format of this program, of which there is a full listing in appendix 11, was designed to be different from the other programs used in these studies. It was designed as a game, where the simulation is that of a fish farm and a recreational centre for fishing. The commercial aspect of the program, that is the apparent requirement to make a profit over a number of years was included to motivate the students. It can be regarded as a goal towards which the students might aim. To be relatively successful in this game, a sufficiently large population of fish must be maintained over the duration of the game.
I hoped that students would "play" with this program but still acquire as many of the same concepts as in the other POND programs. I hoped that they would show enthusiasm for the learning situation being provided.

It has long been recognised that everyone enjoys playing games, adults and children alike. With the advent of microprocessor technologies, "computer games" have flourished. This explosion of computer games was led by the Space Invaders game. Although many adults view this game as an expensive and time-wasting occupation for the children young adults who spend considerable time and money playing it, it has proved to be of benefit to certain sections of Society in several ways.

It has been widely reported by journalists that developmentally handicapped children have been sufficiently motivated by the game to move hands and fingers in a co-ordinated fashion, whereas before they had not been able to move these parts of their body in such a way. The motivational force of computer games and CAL programs is well-known and its use in special education has been recognised (see for example Brebner and Hallworth [1980] and Cox[1981]).

The captivation of minds by computer games has been studied by Malone (1981). He was interested in how the same things that have made computer games captivating and motivational could be used "to make learning with computers more interesting and enjoyable". From his studies of people playing computer games he developed a set of guidelines for designing highly motivating educational computer programs. He found, for example, that the more obvious the goals of the program, the more popular the game. Scoring, audio effects and
randomness also had high correlations with game popularity. The children liked graphic games and significantly disliked word games. Malone defined three categories of characteristics that make instructional environments interesting:

i. Challenge - for example goals which are personally meaningful, and have variable difficulty levels.

ii. Fantasy - This includes both intrinsic and extrinsic fantasies, the latter being regarded by Malone as more important allowing a student to provide metaphors and analogies that help apply old knowledge in understanding new knowledge.

iii. Curiosity - Programs can stimulate and satisfy curiosity. Learning environments can evoke a learner's curiosity by providing an optimal level of informational complexity with respect to the learner's existing knowledge. The programs should be novel and surprising but not completely incomprehensible. Malone also believes that the programs should be constructive in helping the learners remove the misconceptions that caused them to be surprised in the first place.

In addition to the above, Malone believes that the ability of a person to choose goals is important in making learning fun.
The goals in PONDGAME for the student were to make a profit on the fish farm, and to learn about the pond ecology in so doing. Both of these goals were provided to the student in the text preceding the student's use of the program. In using the simulation it is hoped:

i) that the student's curiosity to find out what happens in certain situations will be excited and thus the student will produce new goals for himself,

ii) that the students will have intrinsic fantasies as they use the program imagining that they are, indeed, running a fish farm.

By aiming to make a profit, by being curious as to what happens when..., and by living in an imaginary world provided by the game it is to be hoped that the students will use the program sufficiently to learn about the model to make "enough" profit and also to satisfy the academic goal, that of learning about pond ecosystems.

4.2.4 POND2HELP

As with the other three programs in the series, this program, of which there is a full listing in appendix 12a, is a modification of POND-2. The difference between POND-2 and POND2HELP is that in the latter program I have included a system whereby help can be provided to the student if they so choose.
The determination of a suitable suggestion of help to the students is made using what I have called a "level of understanding" (L.O.U.). The L.O.U. is determined by asking the student to state whether certain statements are true or false. These statements, as I will show later, are arranged in a hierarchy which I believe might assist the students to work efficiently through the program. Appendix 13a shows the flow-charts of the design of those parts of the program concerned with providing guidance or help to the students.

Many workers (for example Gagné and Ausubel) believe that concepts should be acquired in an ordered manner by a hierarchical presentation of the concepts. If there is such a thing as a "best way" to acquire a set of interrelated concepts, then it is to be hoped that such a program as POND2HELP will help to test the truth of this statement. In POND2HELP I have used a hierarchy of twenty one concepts. This I hoped would allow me to determine which of the possible seventeen levels of understanding, a student appears to be at in any one point during their program-run, and to see whether their progress through the "hierarchy" was at all linear.

These twenty one concepts were chosen since I believe they are important for a good understanding of the concept "food pyramid". However, not all of the twenty one concepts are valid, several are invalid concepts in the context of the model being used in this program. I included these invalid concepts because, as I shall show in later chapters of this thesis:

(a) I found them to be frequently possessed by the students who have used POND-2, PONDU and PONDGAME, and
(b) because I believe it to be necessary to determine whether such a concept is possessed by a student. Once it has been determined that a misconception is possessed by a student, the student might be encouraged to acquire the valid concept.

The order, or hierarchy, I have chosen is a personal choice. However, it is a choice heavily influenced by the order in which I found these concepts to have been acquired by students. Figure 4.4 shows the concepts, or groups of related concepts, at each of the levels of understanding. This hierarchy was derived from the network of concepts shown in figure 4.5.
Figure 4.4 The Level of Understanding of the Concepts used in PONDHELP
Figure 4.5: A network of concepts related to the food pyramid concept.
From figure 4.5 it can be seen that the students appeared to work in the previous programs (POND-2, PONDQU and PONDGAME) from a knowledge that the organisms were interdependent to an idea of how the numbers of each of the trophic levels were interdependent to a more exact or specific notion that the numbers were related because one population fed of another population. This is followed by a realisation that the plankton photosynthesise, and that the plankton can live in the pond without fish or herbivores.

In the hierarchy shown in figure 4.4 I have regarded this ordering of the concepts to be the most important, and thus should come earlier in a linear hierarchy. I have followed this progression of the concepts by concepts concerned with an equilibrium, and how pollution affects this equilibrium.

The student's Level of Understanding is determined at the start of the program, and whenever during the program-run s/he decides "not to continue". Appendix 12b describes how the Level of Understanding is determined in the program.

The various levels of guidance provide comments and suggestions for future tasks which the students could, if they so desire, choose to do. These comments can ask the students to question ideas or concepts they appear to possess, and perhaps experiment with the model to find out whether this idea appears to withstand such a test.

If the student does not find the comments and suggestions useful then they have the opportunity to ask for another set of comments and suggestions. These comments and suggestions are provided at a level
lower than those immediately presented. Two sets of comments and suggestions at any one point in the program-run is the maximum offered. The student has the choice of either accepting these suggestions and designing combinations of INPUT values which might, for example, test a particular hypothesis, or of ignoring what has been suggested and carrying on with the program using their own ideas concerning how the program should be used.

The sets of comments and suggestions which are provided to the students at each level of guidance is shown in appendix 13b.
Chapter 5

The 'POND' Programs as a Teaching Medium

5.1 Introduction

In this chapter I intend to provide an overview of how the students regard and make use of the POND programs. There are four aspects that I want to consider here:

a. The aims of the POND programs as perceived by the students. These aims, objectives or goals play a large part in directing a student's activities during their use of the CAL program.

b. The knowledge that a student can gain through the use of a CAL program is dependent to a large extent on the information that is displayed on the V.D.U. or hardcopy printout as a result of the computer's activities being governed by the program. I have already discussed (4.1.2) the various forms in which data can be output by the computer and the resulting effect it might have on learning. In this chapter I intend to investigate student's views regarding various forms of data presentation, including those used in the POND programs.
c. Having determined the apparent goals of students and the effect that the form of data presentation may have on the body of knowledge acquired by a student, I want to examine the development of the concept "food pyramid" through the use of these programs.

d. Finally, I want to examine how the attitude of students to the teaching of the food pyramid concept might be changed as a result of using the programs, and how these attitudes might be different as a result of using programs of different styles and structure.

By looking at these four different aspects of the POND programs, I hope that an overall picture of these programs will be given. This will be followed in part three of this dissertation by a more detailed examination of the learning process in the context of CAL.

5.2 Student Perceptions of the Aims of the 'POND' Programs

5.2.1 Methodology

The students participating in these studies were all subjected to the same routine of being interviewed before and after their use of a POND program. In the post-run interview I asked the question "What do you think are the main points that were brought out by the program?". Their replies to this question were examined by item analysis. The interview transcripts were examined, the relevant points being underlined and categorised in the following manner:

"Life in a pond. How the levels varied with different animals, phytoplankton, herbivores and fish. How they varied if you altered things"
Twenty "main points", or program aims, (labelled a-w [see appendix 14]) were distinguished. These points included "nothing" (a), "numbers in a pond vary" (h), "'factors' affect ecosystem" (g), "to compare/alter statistics" (l), "financial gain" (m), and "problem-solving" (o).

With so many "main points" I thought that it might be more meaningful to group together similar points. Six such groupings were obvious:

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Points included in Group</th>
<th>Relationship of points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>a</td>
<td>No points made by program.</td>
</tr>
<tr>
<td>2.</td>
<td>b,c,h,i,f,s,u,t</td>
<td>Concepts related to the kinetics of the food pyramid</td>
</tr>
<tr>
<td>3.</td>
<td>g,r,d,k,q,e,v,p</td>
<td>Concepts related to the factors affecting the stability of the ecosystem.</td>
</tr>
<tr>
<td>4.</td>
<td>l,w</td>
<td>Compares statistics or the use of graphs &amp; tables.</td>
</tr>
<tr>
<td>5.</td>
<td>m,v</td>
<td>Financial.</td>
</tr>
<tr>
<td>6.</td>
<td>n,o</td>
<td>Forward planning or problem-solving.</td>
</tr>
</tbody>
</table>
5.2.2 Results

Figure 5.1  Student perceptions of the aims of the POND programs
From Figure 5.1 it can be seen that there is a change in the way that students view the purpose of each of the four 'POND' programs. POND-2 and POND2HELP were viewed in a very similar way to each other, the students placing a slight emphasis on the concepts related to the kinetics of the food pyramid, that is the "life in the pond", rather than those points which include factors affecting the stability of the ecosystem. This is well exemplified by the following quotations:

"I saw that the normal life, the natural life of a pond does not vary much between the years, but the effects that fishing has on it can be quite dramatic, and can change the balance of life a lot. Also pollution has a major effect initially, but the balance of life returns..."

(DW - POND-2)

"That all the organisms were interdependent of each other...and that the fishing rate has an effect on the fish population and the numbers of herbivores and phytoplankton in the pond. The phytoplankton, fish and herbivores reach an equilibrium with each other."

(RC2 - POND2HELP)

The students' perception of PONDQU was similar to that of POND-2 and POND2HELP. However, the emphasis was on the factors affecting the "balance of life" rather than on the "life in the pond".

"Well I thought, personally, nature really is quite fantastic actually. Everything will compensate even with man polluting the thing, the thing will live...That was the main thing, well the numbers changed, but in general kept the order."

(CP - PONDQU)

The most dramatic change to the 'POND' programs was in the design of PONDGAME. This was also the program which the students viewed quite differently from the other three. Here, the purpose was seen not so much as to acquire ecological concepts, but that of making a profit and/or as a problem-solving exercise. The presentation of similar, but not identical, simulation programs can thus quite dramatically
affect how the learning material is regarded by the students:

"To see how you were able to compare the statistics, I think. Rather than any biological significance."

(JH - PONDGAME)

"trying to get to think in advance..."

(SE - PONDGAME)

"...it didn't really have anything to do with fish farming really...It made you think about how you could alter those statistics...How you could influence...like the stock and profits...I looked upon it more as a business proposition than a...ecological exercise."

(CH - PONDGAME)

It thus seems that the first few lines of the introductory exposition provided by the program PONDGAME

"This program is a simulation of a fish farm. You are required to find out as much as you can about the ecology of the pond you manage."

went unheeded by many of the students. Greater emphasis seems to have been placed on the next line of this exposition:

"However, the farm should make a profit."

This is not to say that some of the students did not see this program as being mainly concerned with pond ecology:

"It's trying to teach you to get the right amount of herbivores and plankton for the fish."

(RC1 - PONDGAME)

But, as might now be expected, even this student (RC1) appreciated the financial aspects of the program:

"Obviously you want the fish to increase and get a profit on the farm...to keep the fishermen happy."

(RC1 - PONDGAME)

With this emphasis on making a profit, it was necessary, as one of the students (RC1) said, to keep the numbers of fish at a high level. However, I had designed the program so that it was not possible to make a continual profit. By removing fish by one of the two methods available (fishing and by "harvesting") the fish numbers would decline, and after several years at the most, the profit being made would change
to a loss. I thus hoped that the students would respond by trying to increase the numbers of fish by using their knowledge of how the ecosystem works, being motivated by the goal of making a profit.

Some of the students had a noticeable change of goal during their program run. Four of the seven students who used PONDGAME had the "profit" as their only goal throughout the program run. The three other students had at least one change of goal throughout their use of the program. One student (JH2) initially started by wanting to make a profit but then realised that he should understand more about the ecology:

"I think I should have done it the other way round, because by the time I got on to finding out what they were actually doing other than pressing the fun buttons then it really was too late."

Another student (AY) started in the way that JH2 had wished to start, that is by studying the ecological aspects of the model. Although his aim changed from this to wanting to make a profit, this aim wasn't so strong as the initial one:

"What lost $400? I can't see that. Not bothered about that anyway. The fish increase anyway."

The third of the students (CH) who changed their goal during their program-run, started by wanting to make a profit, then went on to have a look at the ecological aspects of the model:

"I don't know. I can't think what to do really. I could try fishing again. The problem is to increase the stock. And short of not doing anything I don't see how you can."

It was at this point of desperation that she made apparent the feeling, or understanding, that everything in the pond is balanced unless extrinsic factors affect this equilibrium. Once she had realised this, her strategy became apparent:
"I suppose I could get rid of the plankton, I can't see the advantage of that at all... It's all a game... I'm going to reduce the plankton and see what happens. I haven't much faith in it. Perhaps they were doing something."

Even though CH was trying here to see the effect of varying a parameter on the ecosystem model, it is apparent that she still has in her mind the desire to make a profit, a point she later made in the interview:

"I looked upon it more as business proposition than a... ecological exercise."

After experimenting to find more about the ecological model, CH went back to trying to make a profit.

Another way in which this overriding desire to make a profit affects the strategies that the students employ using PONDGAME can be seen in the low proportion (19%) of the outputs that were involved with some form of pollution (see Figure 5.2). Why should the students choose to pollute their ecosystem? Pollution kills the fish and other pond organisms, and then the profit disappears!
Table 5.2.2

<table>
<thead>
<tr>
<th>Program</th>
<th>Percentage of the total outputs concerned with</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pollution</td>
</tr>
<tr>
<td>POND-2</td>
<td>41.3</td>
</tr>
<tr>
<td>PONDQU</td>
<td>34.0</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>18.8</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>28.4</td>
</tr>
</tbody>
</table>

Figure 5.2 Percentage of outputs involved with pollution for each of the 'POND' programs

Figure 5.2 shows that although the frequency of outputs involving a low pollution is approximately the same as for the other 'POND' programs, it decreases quite markedly for the higher levels of pollution where a marked effect on the various pond organisms, and especially the fish, could be predicted. Comments such as in the following quotation exemplify the students' attitude towards pollution when using this program:

"Don't want any of that." (RC1)
"Well, if you have a choice really you don't really want pollution do you?"

(SE)

"I don't think I'll give myself problems...I don't know why you ask this question. I'm reluctant to use it."

(CH)

On the other hand, for a more complete understanding of ecosystems and the adverse effect that pollution can have on the flora and fauna, students should be encouraged to observe the behaviour of the model when it is subjected to pollution.

It seems that in a game situation, anything which could act against the best strategy to "win" the game will not be used greatly even if of educational benefit to the students. On the other hand, in the more normal simulation programs, the aims or goals of the students are apparently those that one would wish a student to have if they are to obtain benefit from using the program.

5.3 Student Preferences for Data Presentation

5.3.1 Introduction

The purpose of a graph is to display and communicate numerical information. But what is a graph? Janvier (1978) has defined a graph (or more accurately a Cartesian graph) as:

"...any graphical representation which makes use of two orthogonal axes - even implicitly."

Graphs have evolved over many centuries as a means of displaying data in mathematics and statistics. It is also used in other areas such as geography, economics and advertising.
Biology, however, has been traditionally thought of as a descriptive science rather than a "scientific" and quantitative subject. Many adults and children, I suppose, still view biology today in this traditional vein, and it is thus often viewed as a "soft" option as a school subject. However, biology during the last twenty or thirty years has evolved from being a study of natural history to being a laboratory-based subject where skills in many scientific areas such as chemistry, physics, mathematics and statistics are required.

The importance of mathematics to "modern" biology is varied. It is used in the modelling of biological and ecological systems, in statistics and in other topics. As a result, its introduction to children studying biology in schools should be of prime importance to the biology teacher. It should be introduced in such a way that the children are not frightened by it.

Many biologists, however, are averse to using mathematics in their biology. The importance of mathematics to biology is seen by the various GCE examining boards who often include quantitative-type questions in their examination papers, especially at Advanced Level. Dudley (1977) made a study of a range of mathematical topics in GCE O/L and A/L biology examination papers. At O/L graphs have a 70% incidence, at A/L a 40% incidence. At O/L, axis scales are not brought in at all, at A/L they have about a 7% incidence. This would seem to indicate that very little is expected by the examiners of a student's ability to interpret graphs, even at A/L. It may be that the higher cognitive skills of graph interpretation are not required because it is realised that the majority of biology students at this level would be unable to succeed in these tasks.
Teachers often comment that students of school-age are unable to demonstrate the various skills used for the interpretation of graphs. Such skills might be the ability to select scales, plot points, read co-ordinates, interpret and make predictions from graphs.

Dudley (1977) also recognised that there is a difference in the emphasis placed by mathematicians and biologists on the way that they use graphs:

"It is the relationship that a graph exposes, and especially the equation of that relationship, that takes the attention of mathematicians. It is the "story" that the graph tells that takes the attention of the biologist."

Biologists generally do not view graphs as a means of expressing a mathematical relationship. Instead, they see graphs as a means of presenting or communicating trends within their data.

When graphs are used as a means of obtaining information about trends, relationships and so on, is there any evidence concerned with the style of presentation that students prefer? Schutz (1961) has looked at various methods of presenting graphs, for example by lines and points, and has found that for examining trends and obtaining general information, the multiple-line graph is by far the superior format for the purpose of biological interpretation.

Many teachers use different colours for the various lines on a multiple-line graph. Recent microcomputers, such as the BBC computer introduced into many schools and other educational establishments, also have this facility. How effective is the use of colour as a means of graph clarification? Schutz (1961) studied the effectiveness of four
different colours (red, yellow, green and purple) for each line type. Although most teachers would admit to the belief that colour aids the clarification of pictures and diagrams, Schutz's studies indicate that it did not have any profound effect if compared with a highly discriminable black and white line code. If the line code has been less discriminable then the effect of coloured lines might have a more profound effect. However, Schutz did not investigate this.

Reid and Miller (1980) have carried out more recent studies on the effect of colour on the perception of biological pictures by students. A graph can be regarded as a pictorial representation of numerical data and thus can be likened to the diagrams used in biological texts. Reid and Miller found that a high level of complexity in a picture will lead to an inhibition of observation, and presumably therefore, understanding. They also found that colour can enhance the observation powers of children of average ability looking at pictures of average complexity. The conclusion Reid and Miller came to was that colour is able to compensate for ability only under certain circumstances when it will prove advantageous for the student looking at the diagram or the graph.

Graphs used in the POND programs have a multiple-line format. This necessitates the student being able to:

i. Read the co-ordinates of a point,

ii. Read and interpret the scales on the axes,

iii. Interpret the changes in decrease or increase in slope of the lines as a change in population size,

iv. Make comparisons between the behaviour of each population and thus be able to hypothesise that:
a) a relationship between certain populations exists, and
b) the nature of the relationships between the populations in the ecosystem,
v. Hypothesise the effect of various environmental factors on each of the three populations in the pond ecosystem.

5.3.2 The Presentation of Numerical Data by the POND Programs

In the POND programs, three forms of numerical data presentation are used. Namely, a tabular output (Figure 3.3), a low-resolution form of graph (Figure 3.2) and a "high"-resolution graph (Figure 5.3)
The students are normally given a choice in the POND programs between a tabular or graphical form of data output. The exception is where the ecosystem is being polluted which results in the number of phytoplankton increasing by a hundred-fold, going off-scale on the graph and thus causing the program to "crash". Whenever pollution is chosen, therefore, the program automatically selects a tabular mode of data presentation.

The decision to use high or low resolution graphs is one which was made not by any personal preference, but by hardware limitations. A "high" resolution form of graph could not be included in the programs until after I had written and started using PONDGAME, when suitable hardware became available for PET microcomputers. I introduced high-resolution graphics to some of the students using PONDGAME during their post-run interview to try and obtain some idea as to how they compared it to the low-resolution graphs they had been presented with during their program run.

<table>
<thead>
<tr>
<th>Program</th>
<th>Type of graph</th>
<th>% preference for graph</th>
<th>% outputs using graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>POND-2</td>
<td>LRG</td>
<td>22.2</td>
<td>14.2</td>
</tr>
<tr>
<td>PONDQU</td>
<td>LRG</td>
<td>22.2</td>
<td>35.1</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>LRG</td>
<td>0.0</td>
<td>16.0</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>HRG</td>
<td>70.0</td>
<td>64.2</td>
</tr>
</tbody>
</table>

Figure 5.4 Use of graphs by students using the POND programs
When asked in their post-run interview which of the two formats, table or graphs, they preferred, the students showed a significant difference depending on which program they had used. The students who had used the programs (POND-2, PONDQU, PONDGAME) which had a choice either of a table or a low-resolution graph showed a marked preference for the tables. Indeed, those students who had used PONDGAME had a 100% preference for the tables or a reason I will demonstrate later. Those students who used POND2HELP had a marked preference (70%) for the high-resolution graph.

During the interviews I tried to ascertain the reasons why students liked or disliked particular graphical presentations. The main points of their replies are shown in figure 5.5.
### Graphical Type of Presentation

<table>
<thead>
<tr>
<th>Reasons for Frequency</th>
<th>Reasons Against Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. See relationships, Visualisation 10</td>
<td>1. Confusing 10</td>
</tr>
<tr>
<td>2. Information clearly presented 4</td>
<td>2. Graphical symbols (F,H,P) not understood 7</td>
</tr>
<tr>
<td>3. More compact 1</td>
<td>3. Didn't understand x and y scales 5</td>
</tr>
<tr>
<td></td>
<td>4. Graph twisted through 90 degrees 4</td>
</tr>
<tr>
<td></td>
<td>5. Inaccurate 3</td>
</tr>
<tr>
<td></td>
<td>6. Didn't understand graphs 2</td>
</tr>
</tbody>
</table>

### Tabular Type of Presentation

<table>
<thead>
<tr>
<th>Reasons for Frequency</th>
<th>Reasons Against Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Can compare numbers 11</td>
<td>1. Have to concentrate more 4</td>
</tr>
<tr>
<td>2. Clear and concise 6</td>
<td>2. Too many figures, confusing 3</td>
</tr>
<tr>
<td>3. Easier to use and understand 4</td>
<td>3. Can't see trends 2</td>
</tr>
<tr>
<td>4. Better illustration 2</td>
<td>4. Difficult to distinguish levels 1</td>
</tr>
<tr>
<td>5. More accurate 2</td>
<td>5. Inaccurate 1</td>
</tr>
<tr>
<td>6. Prefer to work out something from tables 1</td>
<td>6. Can't see relationships 1</td>
</tr>
<tr>
<td>7. Easier to memorise 1</td>
<td></td>
</tr>
<tr>
<td>8. Familiar with tables 1</td>
<td></td>
</tr>
<tr>
<td>9. Don't have to visualise 1</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.5** Student Preferences and Dislikes of Graphical and Tabular Methods of Data Presentation
The majority of the students saw the tables in these programs as having a number of uses or advantages over the low-resolution graphical form of data presentation. Their opinions varied from tables being clear and concise (6 students) to not having to visualise the data (1 student). However, the students saw the facility of being able to compare numbers when using the tables as being the most important advantage of their use (11 students). Graphs, of course, are not intended to convey exact numbers, but rather trends and relationships.

Student views of the low-resolution graphs were usually against the use of this format rather than for its use. The main reasons appeared to be that they were seen as being confusing because of the multiple-line format where the "lines" for each population are only represented by upper-case letters (F,H,P). Initially this means of line representation is confusing, but with some practice and experience the amount of confusion is greatly reduced.

They also disliked the graphs being twisted through 90 degrees from the "normal" position.

Students using the high resolution graphs in POND2HELP had a completely different attitude. No mention was made of confusion in interpreting the lines, which are easily distinguishable. The only difficulty that some of the students using this program had, and also the other three POND programs, concerned the "y-axis" scales. It was necessary, because of the multiple-line format, to have a separate "y-axis" scale (see figure 5.3) for each of the three populations.
Some students had difficulty in interpreting the data because of this y-axis presentation. Some students realised this; others had not realised that they had any difficulty with these axes, but from the post-run interviews I suspect that a considerable number had been reading these scales incorrectly during their program runs.

Opinions regarding the advantages of using a graphical form of data presentation were mainly concerned with the ability to see relationships and ease of visualisation. That is, the students could see the trends; they could see the numbers going up and down; they could see one population increasing or decreasing just after another.

To summarise these results, I would say that the majority of the students preferred a tabular output rather than a low-resolution graphical output first because the tables enabled the sizes of the populations to be compared, and secondly because the students are more familiar with tables and because the low-resolution graphs were confusing. With the provision of high-resolution graphics, the body of student opinion changed. Most now preferred the graph because the information was presented more clearly than in the tables.

It is also interesting to note that:
the goal of the program can be an influencing factor on the choice of data presentation.

Students using PONDGAME all preferred to use a tabular method of data presentation because it was necessary to see the numbers rather than the trends and relationships.
5.3.3 Student Preferences for Scientific Data Presentation

5.3.3.1 Introduction

After obtaining the results given in 5.3.2, I decided to investigate further student preferences for, and opinion of, various forms of data presentation. I was interested in determining how GCE A/L science students felt about various methods of tabular and graphical forms of data presentation.

I felt here that four questions should be answered:

i. Do all science (biology, chemistry, and physics) GCE A/L students view the various forms of data presentation often found in computer outputs in the same way?

ii. Do students have the same attitude to single-line and multiple-line graphs?

iii. Do students have different attitudes to the various forms of data presentation which depend on the amount of numerical information being presented? For example, do students prefer a tabular display of data for both single and multiple sets of data?

iv. How does the method of presenting a graph affect student attitudes? For example, do they prefer high-resolution to low-resolution graphs? Continuous lines or "lines" formed by discrete symbols?
Methodology

The answers to these questions were sought by means of a questionnaire (appendix 15) given to all of the GCE A/L students studying physics and biology at Guildford County College of Technology. This sample of students would include students also studying chemistry.

The questionnaire asked for certain personal details of the students concerned with the courses they were taking. It then presented eight different forms of data presentation. Figures 1 to 4 use a similar single set of data. Figure 1 is a simple table; Figure 2 a typical low-resolution, single-line graph as would be presented on the Commodore PET or on other primitive microcomputers; Figure 3 is similar to Figure 2 except that the letters representing the points of the graph are replaced by a cross, and that the y-axis scale represents numbers/cm$^3$ rather than numbers x 10$^3$/cm$^3$; Figure 4 is a "normal" single-line graph, but like Figure 3 the y-axis scale is numbers/cm$^3$. Figures 1 and 2 thus represent the same numerical information, whereas Figures 3 and 4 are representations of data a thousand-fold less in magnitude. Figure 5 to 8 are representations of an identical multiple-set of data. Figure 5 is a four-column table; Figure 6 is a high-resolution graph oriented 90 degrees from "normal"; Figure 7 is a low-resolution graph also oriented 90 degrees from "normal", also the points of the graph are given by upper-case letters as used in the POND programs; Figure 8 is a high-resolution graph oriented "normally".
Questions A1 to A10 and B1 to B10 asked by the questionnaire give the student a choice of two forms of data presentation and the students are required to select their preferred form. They are also asked why they have their choice. Questions A11 and A12 and B11 and B12 are concerned with determining whether or not the students can tell whether there are any differences between the four forms of data presentation, and if so, what the difference is.

In Section C of the questionnaire I wanted the students to rate not only their own preferences for forms of data presentation according to a 0 (Not at all) to 10 (Very highly) scale, but also to imagine how other people (mathematicians/physicists and biologists) might rate them.
5.3.3.3 Results

Fifty questionnaires were returned. This represented an approximate return of 45% of those distributed. Student replies were summarised on master sheets, reasons for preferring particular forms of data presentation were categorised, the various categories being also noted on the questionnaires.

The questionnaires were separated into three groups, the results of which were recorded separately:

i. Biologists not studying physics,

ii. Physicists not studying biology,

iii. Biologists studying physics.
### Single-set data presentations

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Biology only</th>
<th>Physics only</th>
<th>Biology + Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table v. LRG</td>
<td>11-4</td>
<td>15-5</td>
<td>11-4</td>
</tr>
<tr>
<td>Table v. HRG (point)</td>
<td>10-5*</td>
<td>13-7</td>
<td>7-8</td>
</tr>
<tr>
<td>Table v. HRG (line)</td>
<td>4-10</td>
<td>5-15</td>
<td>3-12</td>
</tr>
<tr>
<td>LRG v. HRG (point)</td>
<td>1-11*</td>
<td>2-18</td>
<td>1-14</td>
</tr>
<tr>
<td>HRG v. HRG (line)</td>
<td>1-13*</td>
<td>3-17</td>
<td>1-14</td>
</tr>
</tbody>
</table>

### Multiple-set data presentations

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Biology only</th>
<th>Physics only</th>
<th>Biology + Physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table v. HRG (twisted 90°)</td>
<td>10-5</td>
<td>11-9</td>
<td>8-7</td>
</tr>
<tr>
<td>Table v. LRG</td>
<td>15-0*</td>
<td>20-0</td>
<td>14-1</td>
</tr>
<tr>
<td>Table v. HRG (normal)</td>
<td>5-9*</td>
<td>5-15</td>
<td>4-11</td>
</tr>
<tr>
<td>HRG v. LRG (twisted)</td>
<td>13-0</td>
<td>20-0</td>
<td>15-0</td>
</tr>
<tr>
<td>LRG v. HRG (normal)</td>
<td>0-14*</td>
<td>1-19</td>
<td>2-13</td>
</tr>
</tbody>
</table>

* students undecided account for discrepancy in numbers

**Figure 5.6** Student preferences for forms of data presentation

<table>
<thead>
<tr>
<th>rating value</th>
<th>No. students rating methods of data presentation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low res. graph</td>
</tr>
<tr>
<td>0 &quot;Not at all&quot;</td>
<td>19</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>10 &quot;Very highly&quot;</td>
<td>1</td>
</tr>
</tbody>
</table>

**Figure 5.7** Rating of forms of data presentation by GCE A/L students
The students did not see low resolution graphs to be of very much use, whereas both of the other forms of data presentation were rated very similarly as being very highly useful.

From Figure 5.6 it can be seen that for both single and multiple sets of data, tables were preferred by the majority of the students, except when a "normal" high-resolution graph was provided. The main reasons for this preference for tables were concerned with accuracy and clarity. However, when the tables and high-resolution graphs were compared by the students, the main reasons given for preferring the latter form of presentation were that it was easier to see the trends and relationships, to compare data, and to understand the data because of its clarity. This feeling was even stronger for the graphs showing multiple sets of data.

Low-resolution graphs, other than hand, were very rarely preferred as a form of data presentation. Often the students referred to these graphs as being "jumbled mass of points" for example. The other point often made by the students concerned their inaccuracy, for example:

"The point B could give a reading in an area around the B, that is there is no precise value unlike figure 1 where a graph could be plotted and values accurately taken."
There appears to be very little difference in opinion of students who studied biology (but not physics), and those studying physics (but not biology). However, when one group of students predicted how useful the various forms of data presentation might be to a mathematician/physicist and to a biologist, some mildly interesting results became apparent, especially with the physics students. Figure 5.8a, for example, shows that the physics group of students believe that the low resolution form of graph would be of very little use to a physicist. The spread of opinion was much wider for their use to a biologist, some students giving a rating value of 9 (almost "very highly" rated). This trend is also to be seen in Figure 5.8b, but in reverse. Here the physics group of students see biologists having less use for a high-resolution graph than do mathematician/physicists.

The ability of students to understand and interpret numerical information is important. The students were asked on the questionnaire to distinguish which forms of data presentation are different from the others. This yielded interesting, but not really unexpected, results. It was found that only 30% of the physics group of students were able to give the correct answers, and only 13.3% of the biology group.
Figure 5.8a  Student perceptions of the use of low-resolution graphs

Figure 5.8b  Student perceptions of the use of high-resolution graphs
5.3.4 Recommendations for data presentation in CAL programs

Computer Assisted Learning largely depends on the synthesis of numerical data by the computer and its presentation by the program, via the computer, to the students. To obtain the maximum educational gain from the program, the students must be familiar with the form of presentation of the numerical information, whether it be a table, a pie-chart, a histogram, a graph etc. Indeed, the students need not only to be familiar with these forms of data presentation, but also need to be adept at obtaining the information implicit in that data.

In producing a CAL program, the author must be guided by a number of important factors concerning the presentation of the numerical data, namely:

i. The students for whom the program is designed,

ii. The hardware on which the program will run, since this may only allow, for example, the poorly regarded low-resolution graphics,

iii. The purpose of the data, for example, whether it is intended for numerical manipulation or as a means of communicating information?

The choice of data presentation where the student is to be "informed" may be left, within certain limitations, to the student using the program. The student can then choose the style of presentation that they prefer and from which they believe they can obtain the most information.

Such a choice of style of data presentation may be affected by a student's previous education and training as well as by the design, say, of the graph or of the table of results.
5.4 Development of the Food Pyramid Concept: Initial Findings

In section 5.3 I looked at the presentation of data on the VDU. In this section I want to look at the effect of programs on cognition. Cognition, understanding the behaviour of the simulation model should result from viewing the data presented on the VDU. I want to look at the definitions and examples of food pyramids given by the students participating in these studies before and after the program run. This constitutes a preliminary investigation of the development of the concept "food pyramid" and how this developmental process may vary with program structure.

The students were asked to provide a definition of a food pyramid in their interviews before and after using a POND program. The definitions were examined:

i) by looking for specific concepts subsumed under the concept "food pyramid". Here I elicited fourteen concepts which the students appeared to have developed.

ii) by categorising the fourteen concepts elicited as described in (i) into groups of similar beliefs. The concepts were assigned to one of seven such groups:

A. No definition provided.
B. A general food chain.
C. A specific food chain.
D. An idea of a dynamic ecosystem (that is, the numbers of a particular population are determined by other populations in the ecosystem).
E. Somehow numbers are involved (may be just a statement of population size - but no mention of a dynamic system).

F. Represents a "need for food".

G. Energy involved.

It was by this second method that I achieved most success in that it was easier to categorise the nature of the conceptual understanding shown by the students' definitions. The definitions provided by the students often didn't show any specific, easy-to-describe conceptual understanding. It was however, possible to see within the student's definitions ideas being made explicit in a rather poor way. For example:

"It's the way animals feed on each other, and the transfer of energy downwards. It goes upwards! It goes from the phytoplankton upwards. So the most is at the bottom and the least at the top." (AB)

In this attempt at a definition, the student is conveying the idea:

i. that the animals feed on each other [1], and

ii. there is a food chain (of animals) through which this energy is transferred [2] - the phytoplankton being at the base of the food pyramid.

I have said, for example for this definition provided by AB, that the student was trying to present a general description of a food chain (group B concepts), that energy is involved in the food pyramid (group G concepts) and also trying to put over the idea that somehow numbers are involved in the food pyramid (group E concepts). In other words, I have not thought it necessary to provide an explicit and accurate description, but merely to put forward some idea of what I believed the student to be trying to say. By attempting to determine the general ideas rather than specific concepts. I hoped to get a more valid overview of what the students believed a food pyramid to be. For, as
one student said:

"I have got a picture of it in my mind, but putting it into words is difficult." (SA)

<table>
<thead>
<tr>
<th>Program</th>
<th>No. of students</th>
<th>Percentage of students exhibiting a Conceptual Group Before program run</th>
<th>After program run</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A  B  C  D  E  F  G</td>
<td>A  B  C  D  E  F  G</td>
</tr>
<tr>
<td>POND-2</td>
<td>9</td>
<td>22 78 0 0 0 0 11</td>
<td>11 78 11 11 33 0 0</td>
</tr>
<tr>
<td>PONDQ</td>
<td>9</td>
<td>44 56 0 0 11 0 0</td>
<td>11 78 0 11 44 11 11</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>7</td>
<td>14 86 0 0 29 0 0</td>
<td>0 100 0 0 57 0 14</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>10</td>
<td>0 50 20 0 20 10 10</td>
<td>0 90 0 0 60 10 0</td>
</tr>
<tr>
<td>ALL POND Programs</td>
<td>35</td>
<td>20 66 6 0 14 3 6</td>
<td>6 86 3 6 49 6 6</td>
</tr>
</tbody>
</table>

**Figure 5.9** Conceptual understanding of the concept "Food Pyramid" and its development using the POND programs

An alternative, and perhaps more fruitful was of representing a student's ability, in terms of a definition that they provide, might be to summarise their definition according to a hierarchical ordering of the conceptual statements showing increasing levels of understanding of the superordinate concept "food pyramid". I believe that there are eight levels of understanding which I have described below, and which I have used to follow a student's development through using a POND program:
0. A definition could not be provided.

1. Includes the concept "a need for food", or "involves numbers", or a "involves a transfer of energy".

2. Includes a specific example of a food chain.

3. Includes a general example of a food chain.

4. Includes a specific example of a food chain together with some conception of population sizes.

5. Includes a general example of a food chain together with some conception of population sizes.

6. Includes a specific example of a food chain together with an appreciation of the dynamics of the interrelationships of the various organisms within the ecosystem.

7. Includes a general example of a food chain together with an appreciation of the dynamics of the interrelationships of the various organisms within the ecosystem.

<table>
<thead>
<tr>
<th>after prog.run</th>
<th>Level of understanding</th>
<th>before program run</th>
<th>total after run</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

| total before run | 7 | 2 | 3 | 18 | 0 | 5 | 0 | 0 | |

Figure 5.10 Frequency of students at each level of understanding of the food pyramid concept before and after using a POND program
Figure 5.10 shows that only three students used a specific example of a food chain rather than a general example. This is not unexpected since when providing a definition students are taught to express themselves in general rather than specific terms. It is only when a student has difficulty in generalising that they will revert to a more simple specific example to express their understanding of a concept.

There was a distinct shift in the level of understanding after the students had used the POND programs. More students had the conception that numbers were entailed within the food pyramid concept by using the programs than had before use of the program. This is probably because the POND programs are concerned with the numerical changes in the populations in the pond ecosystem. However, there was a surprising lack of recognition by the students of the dynamics of the ecosystem model and its involvement in the food pyramid concept.

From Figure 5.10 it can also be seen that the students who "made most use of the program" were those who already had some understanding of the concept "food pyramid". Of the eighteen students who started with a level 3 understanding, ten progressed to a higher level: one to level 4, eight to level 5 and one to level 7. It can be said that those seven students who were not initially able to provide a definition (level 0), also made good use of the programs in that they enabled five of them to provide a definition and thus exhibit some level of understanding, one student exhibited a level 7 understanding after the program run. No students showed a lower level of understanding after using the POND programs.
It can thus be seen that just from the definitions provided during the pre- and post-run interviews, students showed an increase in knowledge and understanding of the superordinate concept "food pyramid". Whether or not the POND programs had facilitated this increased understanding by a "transfer" of knowledge through the Student-CAL interaction must have an element of doubt based on the evidence presented here. It may be that using the POND programs merely brings to the forefront knowledge which a student has previously acquired but could not remember or make explicit. However, in part three of this dissertation I hope to present evidence to show that a "transfer" of knowledge does occur through the Student-CAL interaction. Hence the validity of using the phrase Computer-Assisted Learning.
5.5 Student Views of Teaching the Concept "Food Pyramid"

"Imagine that you are a teacher who has to give a series of lessons in ecology. How would you explain a 'food pyramid' to the students?"

This question was asked during the interviews before and after a student's program run. It is a question concerned mainly with how the students would explain a food pyramid. However, it is also a question which resulted in an alternative explanation or definition of the food pyramid concept being provided. However, in this section I am concerned with restricting my comments to "how" the students would explain this superordinate concept if they were teachers.

From the replies of the 35 students who used the POND programs, 15 different recommended methods for teaching the concept were apparent. The frequency at which the students recommended each of the methods before and after their program-run is shown in figure 5.11.

The data shown in figure 5.11, although somewhat interesting to contemplate in itself, can be made more meaningful, I believe, if it reduced in its complexity. There seems to be two very distinct methods of teaching the students are recommending the food pyramid concept to be taught. The first method does not involve student activity other than listening to a teacher and understanding the information that the teacher is trying to convey. As far as the students are concerned, these teaching methods are "passive" ones in the traditional vein of "talk and chalk", that is the didactic approach. The second method involves a greater degree of student participation. The teaching methods are "active" as far as the students are concerned. The process is less teacher-oriented.
### Percentage frequency of recommendation

<table>
<thead>
<tr>
<th>Teaching Method*</th>
<th>POND-2</th>
<th>PONDOU</th>
<th>PONDGAME</th>
<th>POND2HELP</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>80</td>
<td>44</td>
<td>60</td>
<td>44</td>
<td>83</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>33</td>
<td>20</td>
<td>33</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>22</td>
<td>20</td>
<td>22</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>0</td>
<td>22</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* Key to teaching methods:

1. Use examples
2. Describe organisms.
3. Describe feeding habits.
4. Give food webs, draw diagrams.
5. Give numbers in a given ecosystem.
6. Explain why numbers are so. numbers are controlled.
7. Explain how "nature" controls life.
8. Let students draw it, write examples.
9. Give a general to specific description.
10. Let students do field work.
11. Use POND programs as an exercise.
12. Only use POND programs.
13. Students to work out how.
14. Ask students to introduce new ideas.
15. Let students ask questions.

**Note:** 'B' = before program run.
'A' = after program run.

**Figure 5.11** Student recommendations as to how they would teach the concept "food pyramid"
Teaching methods 1, 2, 3, 4, 5, 6, 7 and 9 I have assigned as "passive" methods. Methods 8, 10, 11, 12, 13, 14 and 15 I have assigned as "active" teaching methods. It is interesting not only to note how students normally view teaching, but also how their opinion can change after participating in an active method, for example, by using a CAL program.

<table>
<thead>
<tr>
<th>Percentage of students recommending a particular type of teaching method</th>
<th>MEAN BEFORE (N=26)</th>
<th>MEAN AFTER (N=35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive methods</td>
<td>23.1</td>
<td>16.8</td>
</tr>
<tr>
<td>Active methods</td>
<td>4.4</td>
<td>9.4</td>
</tr>
</tbody>
</table>

Figure 5.12 Difference in proportion of students recommending passive and active styles of teaching for the food pyramid concept
Although there is not much of a decrease in the proportion of students recommending the various passive methods of learning, it is interesting to note that there was an increase in the proportion of students who recommended active methods of learning after using the POND programs. The students often see the necessity for their participation in the teaching/learning process, as the following three quotations show:

"...hopefully they would see it rather than me actually tell them." (CP:PONDQU)

"I would demonstrate something about it...getting them to do something physical or make them think and not have passive learning." (SA:PONDQU)

"It was good fun, yes. Because then it's not just reading it and learning it. You can actually go and use what you have learnt." (HS:PONDGAME)

There was no great difference in these findings when all four of the POND programs were compared as shown in figure 5.13.

It would thus seem that it was the use of a form of learning in which the students were compelled, by the very nature of the Student-CAL interaction, to be active, that influenced about how the food pyramid concept should be taught.
Percentage of students recommending a a particular type of teaching method

<table>
<thead>
<tr>
<th></th>
<th>POND-2</th>
<th>PONDQU</th>
<th>PONDGAME</th>
<th>POND2HELP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive methods</td>
<td>B 25</td>
<td>A 17</td>
<td>B 20</td>
<td>A 15</td>
</tr>
<tr>
<td>Active methods</td>
<td>0 6</td>
<td>3 9</td>
<td>5 10</td>
<td>7 11</td>
</tr>
</tbody>
</table>

**Figure 5.13** Comparison of the POND programs in relation to the proportions of passive and active teaching methods recommended by the students

5.6 Conclusions and comments

In this chapter I have tried to show various aspects concerning how the POND programs might be effective as a teaching medium. Even though CAL programs may be based on the same mathematical assumptions and therefore similar simulation models, the structure of the program and additional text and questions can influence greatly how students view the goal of the learning exercise. These can be regarded as "interfering factors" (Markova [1982]). Factors such as the nature of premises, the emotions and beliefs of the students, all of which can affect the use of the program by a student and thus what is obtained, in terms of knowledge and understanding, by the students using the programs.
It is not only the structure of the program that can play a significant part in the effectiveness of a CAL program, but also the way in which the numerical information is presented. Without being able to understand the method of data presentation, and being able to interpret the data correctly, errors will be made in the formation of propositions and thus in the formation of a student's conceptual structure.

The formation of a correct conceptual structure, although often incomplete for the food pyramid concept, was demonstrated by the usual improvement of the definitions given by the students before and after their use of the POND program. In many ways this method for determining a "level of understanding" of the superordinate concept is in the vein of the traditional pre- and post-test method for evaluation. It did show, however, that many of the students showed an increased level of understanding, and that no student had a lower level of understanding following their program-run. The POND programs had, therefore, in traditional terms, usually been an effective means by which students had increased their understanding of the ecosystem model. Not only had they increased their level of understanding of ecosystems, but they had a change of view of how teaching such a concept should be managed. There was a tendency to recommend more "active" methods of teaching following their use of the CAL program.
PART THREE

CONCEPT LEARNING: IT'S NATURE AND FORMATION IN THE CONTEXT OF CAL
PART THREE

CONCEPT LEARNING: IT'S NATURE AND FORMATION IN THE CONTEXT OF CAL

In part two I showed some of the effects on learning that were promoted by a simulation model used within four different types of program structure. Part three of this dissertation is concerned with examining, in detail, various aspects of concept formation promoted by the POND programs. The aspects of concept learning that I want to consider are concerned with:

(a) the representation of learning using concept maps, hierarchical structures (chapter 7) and my "Interaction Model" of learning (chapter 8);

(b) examining the forms of concept learning, especially those concerned with causal explanations, promoted by the POND programs (chapter 9);

(c) examining whether some of the cognitive activities promoted by the POND programs, which are a form of science simulation program, are a form of scientific activity (chapter 10).
In chapters 7, 8 and 9, I try to describe the development of a suitably
detailed and accurate means of representing the student-CAL interaction
and concept formation. The subsequent analysis of the protocols of
student program runs enabled a very explicit description of the effect
of program structure on cognition to be provided.

The similarity between concepts and hypotheses, concept formation and
scientific methodology is a marked one. Scientific methodology and
scientific hypotheses represent special subsets of concept formation
and concepts respectively, having evolved from man's "normal" cognitive
ability to understand the world in which he lives. Kelly's notion of
"Man the Scientist" also recognises this similarity. In chapter 10,
I look at Peirce's notion of scientific method and how this relates to
the cognitive events that I have described elsewhere. Here the
importance of surprising events in initiating learning and scientific
discovery is described.

The various descriptions of learning provided thus far in this
dissertation have, in the main, not been related to any other studies
of learning. In chapter 10, having shown that there are many
similarities between concept learning resulting from the student-CAL
interaction and Peirce's theory of scientific methodology, I compare my
findings with those of two other people - Ference Marton and Rosalind
Driver.
Marton's findings concerned with the approach students adopt when in a learning situation has much which can be applied to studies of CAL. Meaningful learning should result when a "deep approach" is adopted. The trivial use of a CAL program does not usually lead to meaningful learning and a thorough interpretation of the behaviour of the simulation model.

Rosalind Driver's work has been concerned with the alternative conceptions that pupils develop in a learning situation, especially those concerned with the development of scientific concepts. She has likened the activities of pupils to those of a scientist and recognises the importance of surprising data in the initiation of the learning process. A comparison is made in chapter 10 of this dissertation between my findings for students using the POND programs and Driver's findings or young children in the science classroom.
Chapter 6
The Nature of Conceptual Knowledge:
Its Acquisition and Representation

6.1 Introduction

In this chapter I intend to look at the nature of concepts, some important theories of conceptual acquisition and exchange, and theories of the way knowledge might be structured in the mind. This will provide a background to the major part of these studies, that is, to the nature of the learning process and how to represent these processes.

Kant (1781) maintained that:

"all our knowledge begins with experience, (however) it does not follow that it all arises out of experience."

According to Kant, two forms of knowledge can be distinguished:

a) A *posteriori* knowledge: a form of knowledge that is formed through the senses. The Latin derivation of this phrase summarises how this knowledge is formed - "from what comes after (seeing)", that is, it is formed by inductive processes from effect to cause.

b) A *priori* knowledge: a form of knowledge that is created by deductive reasoning, that is from cause to effect. The Latin derivation of this phrase means "from what is before". This form of knowledge does not necessarily involve any sensory experiences, it is "supplied by the mind in the act of knowing" (Markova, 1982). A priori knowledge is said to have universal, or general, validity.
Complex ideas are produced as a result of the mind considering information provided by the senses. It was Kant who first coined the term "concept" to describe such ideas.

In the case of a posteriori knowledge, concepts are formed by experience; in the case of a priori knowledge, concepts are products of the mind applied to objects as we know them, we only have knowledge of appearances.

During the last twenty or thirty years less emphasis has been placed on teachers providing facts and theories. Instead, teachers have been persuaded to teach concepts. Facts and concepts should be viewed in different ways.

Facts are pieces of information, the data of experience. The possession of facts does not necessarily imply that they are understood. Meaning can only be given to facts when they are related and further knowledge created or synthesised.

A person who has acquired certain concepts has a general notion, has an understanding, of a particular body of knowledge which has been built from a basis of factual information or experience. Therefore, to possess concepts means that knowledge is meaningful.

In schools, the classroom has become less of a place of rote memorisation, and more of a place for experiential learning. This change in emphasis of the role of the teacher, that is from expositor to facilitator, is often credited to the work of Jean Piaget on
conceptual learning in children. It is through the acquisition of concepts, laws and rules which describe the world we live in, that our knowledge of the world is created.

CAL simulations can be regarded as a form of experiential learning. The student gains knowledge of their world through a simulation of part of the world as provided by an "expert". It is thus important to examine how conceptual learning can be promoted through the use of CAL simulations, and how this conceptual learning can be represented, and how this might be affected by the structure of the CAL program.

6.2 Conceptions of the Concept "Concept"

According to Freyberg (1980) concepts are "differentiations of experience", according to Klausmeier, Ghatala and Frayer (1974) they are "ordered information about the properties of one or more things - objects, events, or processes - that enables any particular thing or class of things to be differentiated from and also related to other things or classes of things."

Concepts can be of different orders of generality, belonging to hierarchies. The higher a concept is in a hierarchy, the more general it is. This necessitates the recognition of superordinate and subordinate concepts. Superordinate concepts are general concepts which entail its more specific subordinate concepts. "The attribute of 'power' refers to the extent to which a particular concept facilitates or is essential to the attainment of other concepts."
(Klausmeier, Ghatala, and Frayer, 1974). Many concepts are defined through their relationship with other concepts. The notion of conceptual structure relies on this interrelationship of concepts.

There are two alternative views of the nature of concepts. The first is that concepts are "signs pointing to invariant relations" (Cohen, 1946), that is they are static and fixed. This view of concepts does not take into account any personal differences of understanding in individuals. A more generally accepted view is that concepts are personal understandings about a particular body of knowledge, of events etc.

To say that a person has a concept is to imply that their interpretation is the same as other peoples. However, it must be borne in mind that, according to the constructivist's notion of knowledge, concepts will differ somewhat from person to person. Each person constructs their own understanding of the world. Each person will construct a particular concept by entailing different attributes obtained from different events and exemplars. This has encouraged some workers (for example, Goguen, 1974) to describe the "fuzzy nature" of concepts in terms of fuzzy set theory. Using fuzzy set theory, similar but different meanings can be subsumed under one concept title thus allowing for border-line cases of membership.

Various types of concept and levels of concept attainment have been described. Bruner, Goodnow and Austin (1956) recognise three forms of concept (single-value, conjunctive, and disjunctive) based on the number of dimensions included in the concept definition. Gagné (1977) recognises two categories of concept (concrete and defined) based on
the nature of the concept. Klausmeier, Ghatala and Frayer (1974) and Kempa and Hodgson (1976) recognise four levels of detail at which concepts can be attained. Some concepts can be attained at all four levels, others, because of their nature, may only be attained at one level.

6.3 The Acquisition of Concepts

Bolton (1977) holds that there are two major theories of concept acquisition:

a) A Theory of Abstraction in which the concept is a representation of the generalities which have been observed to occur among many particular perceptions. In some ways this theory is similar to Kant's notion of a posteriori knowledge, and to inductive reasoning.

b) A Hypothetico-deductive Theory in which a concept is formed by having a particular hypothesis about certain features of the environment. Having a hypothesis enables a person to search for particular evidence which supports or invalidates it. These hypotheses are organised, over a period of time, to form a conceptual system. These concepts may be regarded as a priori knowledge.
These two theories have opposite directions of concept acquisition, but are they necessarily exclusive? Does the recognition and acceptance of one philosophy mean that the other cannot be applicable, perhaps in somewhat different contexts? Each theory of concept formation may have its usefulness in describing learning in different milieu and by different individuals.

According to Bolton (1972), experiments in laboratory situations have shown that students are:

"Influenced sufficiently by their experience for their reasoning to differ from that described by a purely deductive system, whilst experiments on inductive reasoning lead to the view that an understanding of the strategies used by adult subjects in attaining concepts involves reference to the higher-order concepts of a logical and deductive nature."

Bolton thus proposes that an alternative theory be found that does not involve a sharp distinction between two modes of thought, that is, inductivism and deductivism. He states that this theory should have two premisses:

a) that the process of thinking should be regarded as a collection and transformation of information, and

b) that its structure should involve a hierarchical organisation of strategies.

Vinacke (1952) has said that a complex theory of concept formation may include both of these alternative and distinctive theories. Indeed, he sees inductive and deductive processes to be mutually operating activities.
Much time has been spent by philosophers of science on the investigation of science and the methodology, or methodologies, employed by scientists when making observations. For many philosophers of science the inductivist approach is not seen as being representative of those methods. Instead, hypotheses are seen to arise in the minds of scientists and are then either confirmed or rejected according to the results of experiments designed to test these hypotheses.

The formation, or creation, of these hypotheses is usually not seen as being of importance to the philosopher of science. Indeed, Karl Popper (1980) says of the process of hypothesis formation:

"The initial stage, the act of conceiving or inventing a theory, seems to me neither to call for logical analysis nor to be susceptible of it."

Popper distinguishes sharply between the process of conceiving a new idea, and the methods and results of examining it logically. He sees every discovery as containing an "irrational element" or a "creative intuition".

Copi (1953) implies more than Popper when he says:

"Logic has nothing to say about the discovery of hypotheses; this process is more properly to be investigated by psychologists."

This distinction between the roles of philosophers of science and psychologists in discovery and describing the process of hypothesis formation and validation is one which must hinder our understanding of the whole process.
Hypotheses are, however, constructed so as to relate to the events which initiated their production. Hypotheses are not wild, unrelated guesses. For one small group of philosophers this construction of hypotheses and the subsequent choice of the most suitable one is seen as lending itself to a logical analysis. Foremost amongst these is C.S. Peirce (1839 - 1910). Peirce (according to Fann, 1970) felt that there is a logic of discovery, that there is a conceptual inquiry. Peirce accepted that reasoning towards a hypothesis is usually seen either as not being a form of reasoning, or it is seen as a form of induction.

Peirce's arguments, however, were for a Theory of Retroduction, or Abduction. In such a theory the data, not hypotheses, are the starting point for the natural scientist. Abduction is a process of creating an inference which explains surprising data and then deciding whether that idea is worth accepting. The typical example for illustrating an abductive inference is:

The surprising fact C is observed,

But if A were true, C would be a matter of course;

Hence, there is reason to suspect that A is true.

Peirce sees abduction as being the first stage of scientific method. Deduction is seen as the second stage where the necessary consequences (consequences which can be tested) of the hypothesis are made explicit. The final stage is induction, where the hypothesis is tested by experimentation. Induction, the final stage of scientific inquiry, involves the comparison of predictions made during the second stage with the actual results of the experiment.
Peirce thus sees abduction as explaining data and induction as classifying data, two very different processes. Abduction, he believes, is the only way by which new ideas are created. The hypothesis that is created simply being a conceptual device for stimulating and directing observation. The inductive process can now be seen as a directed process, looking at specific data. Hanson (1971) refers to this directed observation of data as having an "epistemic tube". Observations are not seen as leading to a theory through induction, but leading to the intuitive creation of a hypothesis through abduction. Peirce's notion of induction is somewhat different in that it is seen as a means for providing the evidence for the rejection or acceptance of a hypothesis rather than as a means by which hypotheses are formed.

In accepting that concepts are dynamic entities, that they develop as a result of experience and observation, that they change over a period of time, and that concepts, like hypotheses, are capable of being validated or invalidated, then Peirce's Theory of Abduction has much in common with constructivist epistemology.

Concept learning studies have tended to concentrate on the development of rules which attempt to explain the general principles by which concepts are formed. These rules have usually been developed without an "in-depth" study of concept-learning (1) in a realistic learning environment, for example, the classroom and (2) involving the views of the "learners" and facilitators of learning. Often the theories have concentrated on the nature of knowledge rather than the nature of the process. For example, the work of Gagné (1962) and Ausubel (1968) on the order in which knowledge should be acquired has been mostly
concerned with the structure of knowledge.

Conceptual learning is "meaningful learning", the relationship of new information to existing knowledge. For Gagné, this would mean the presentation of subordinate concepts before the higher, superordinate concepts in subject or learning material. For Ausubel it would mean the central, unifying ideas of a particular body of knowledge being presented first, to act as "advance organisers" for the more specific concepts which can then be presented. Learning, according to this model, occurs by a gradual process of subsumption.

For Mitchell (1982), meaningful learning means relating new knowledge to existing knowledge, which is arranged as a network of concepts. The new knowledge merely expands the existing body of knowledge. Concepts are acquired to satisfy present learning needs based upon previously acquired knowledge. Thus, if a chemist wishes to learn about food he will probably start from the chemical structure of the food and expand into new areas such as the effect of cooking on the food. The chef, on the other hand, will probably start by wanting to know more about the nature of the food, for example how it behaves during cooking, and later acquire some chemical knowledge of the effect of cooking when he is ready to do so. For a chef to start by looking at the chemistry of the food would, in all probability, mean that the learning is not meaningful, for there would be no relevant conceptual structure to which it could be related.
The cognitive theories of concept learning and Peirce's Pragmatic Theory of Abduction assume that the individual first analyses stimuli into attributes. An individual's performance is determined to a large extent by how well they selectively attend to the various characteristics defining the concept. This will depend on the previous experiences of that individual in that he has learnt to discriminate or ignore certain types of attribute.

Vinacke's (1952) description of concept formation is more general than those of Gagné and Ausubel. He sees the subject being exposed to material and interpreting it using one or more of a variety of methods. In time some features stand out, others disintegrate until a concept which is applicable to the attributes is found. Peirce (according to Fann, 1970) would say that when the subject is exposed to learning material, the most reasonable concept (hypothesis), that which best fits the characteristic or attributes, would be selected. Vinacke also points out that an individual may also fail to develop an adequate concept.

Interpretation of sense data involves cognitive strategy. This cognitive strategy is usually recognised as leading to the formation of hypotheses. These hypotheses are tested using sense data until the "correct" hypothesis has been selected.

Various cognitive strategies have been recognised, for example, those of successive scanning, simultaneous scanning, and focusing; a wholist and a partist strategy (Bruner, 1956). In all of these, the strategy involves the matching of perceived attributes with the attributes predicted by the nature of the hypothesis or concept. Some strategies
(eg. simultaneous scanning) involve the individual possessing a number of similar hypotheses which are reduced as the evidence accrues and eliminates unsuitable ones. Some strategies involve the testing of one hypothesis at a time; refutation of the hypothesis may either result in it being changed for a more suitable one, or modification to account for the newly recognised attributes.

Peirce does not see an individual maintaining a large number of possible hypotheses, the "incorrect" ones of which are gradually eliminated. Instead, he sees an individual initially choosing the most reasonable, plausible and economical hypothesis, testing it, and then either rejecting it according to the evidence.

Peirce believes an individual considers three factors when selecting a hypothesis:

i. that it explains the observed data or facts,

ii. that it can be tested,

iii. that it is economical (Peirce's concept of "economy" has a number of facets, but basically, a hypothesis is economical if it is simple and has intrinsic value).

Thus, there appears to be two essential parts to conceptual learning:

a) The generation and testing of hypotheses,

b) The cognition of the common attributes of positive instances.

These two facts of concept learning are similar to Bruner, Goodnow and Austin's (1956) subsets of concept learning:

a) Concept formation, which they describe as the inventive act which the classes are constructed.
b) Concept attainment, which is the search for attributes which distinguishes exemplars from non-exemplars (deduction and induction according to Peirce).

Not all cognitive strategies are equally as successful for conceptual learning. Bourne (1965) has reported some of the differences that occur between "good" and "poor" concept learners. He has found that efficient learners tend to take the attributes of the first positive instance of the concept and include them in the initial hypothesis, that is they employ a wholist strategy. He found that poor learners often fail to modify their hypotheses when there is an incorrect category response; that changes to their hypotheses are less consistent with the available information; that they produce more complex changes to their hypotheses than do good learners.

It might, however, prove beneficial for a person not to change the nature of a particular concept (or hypothesis) whenever an inconsistency is recognised. Gaines (1976) believes that most human reasoning allows a redundancy of data and that it accepts minor contradictions. Such minor contradictions may result from the fuzzy nature of certain attributes which can be entailed within a particular concept. However, rather than include inconsistencies into the conceptual structure, Gaines believes that human reasoning contains their effects and isolates them from the recognised positive attributes of the concept.
6.4 Alternative Conceptions

Whatever strategy a person uses to form, or acquire, concepts, there is a very good probability that individuals will not form identical concepts. Prior knowledge and experience can have a marked effect on the formation of new knowledge.

In a similar manner, Peirce (Fann, 1970) believes that every individual's thoughts and feelings are in some way private to himself, and, in a sense, are him and therefore uniquely his. Peirce also recognises that prior premisses affect not only an individual's perceptual judgements, but also the hypotheses that are inferred from observational data. Peirce's Pragmatic Theory is thus, in many ways, similar to those of Constructivists.

According to Pask's "Conversation Theory" (Pask, 1976a) the two participants in the learning process, the learner and the facilitator of learning (teaching and learning material, teacher, teaching machines, computer programs and simulations, even the individual who is learning) participate in a conversation through which a mutual understanding of a particular body of knowledge is brought about or encouraged. Pask's model is one which recognises various teaching and learning strategies, and which recognises that learning often proceeds from "not knowing" to the state of "understanding". Between these two extreme situations, individuals will have an understanding of the subject matter which is not fully in agreement with that of the "teacher".
Various terms have been used to describe the stage where a learner's conceptual structure contains concepts which do not hold the same meaning for learner and teacher. Driver and Easley (1978) suggest that they should be called "alternative frameworks", Osborne and Gilbert (1980) "alternative conceptions". Helm (1980) uses the term that many teachers at the present time would use, that is, "misconceptions".

There appears to be two ways by which we can look at these concepts which are, to varying degrees, incongruous. The first is that if the individual fails to form the "correct" concept because of a logical inconsistency, then it might be fruitful to refer to the concept as a "misconception".

Learning can be viewed as construction of new understandings based on previous ones. If learning occurs in a social environment such as the classroom then we might presume that as learning progresses, conceptions will become more similar to the conceptions held by "experts". Such a convergence of ideas might occur through a process of consensus constructing. It is unlikely, however, that even between experts, conceptions will be completely identical. If we accept that understanding must progress from simple, commonly accepted, everyday conceptions to experts' conceptions then the concept of "alternative conceptions" and "alternative frameworks" is acceptable.

Gilbert, Osborne and Frensham (1982) have distinguished three "levels of understanding" for scientific concepts: "children's science", "teacher's science", and "scientist's science". Zylbersztajn (1983) has suggested that a fourth form of science "curriculum science" should
be included. Gilbert, Osborne and Frensham (ibid) see the teacher interacting (holding a "conversation" [Pask, 1976a]) with the learner, the result of which may lead to the progression from a child's conception of science to a scientist's (expert's) conception of science.

In biology, one area of work concerned with alternative conceptions has been that of Bell (1981, 1982) who has looked at children's conceptions of the concept "animal". She found that many children used the word "animal" synonymously with the word "mammal". Bell suggested that the difficulty for science students in acquiring scientific meanings might arise from the confusion between the common, everyday meanings. Kargbo, Hobbs and Erickson (1980) and Posner (1981) have even suggested that children may develop two types of mental structure; one for everyday experiences, the other for school teaching. The role of the teacher is to encourage the student/pupil to distinguish between everyday and scientific concepts.

How unique is "children's science"? Is it unique to children or is it a more widespread phenomenon seen in those individuals who have received little training in scientific subjects? When does "children's science" become "lay science"? I will show later that even in College students aged 16 to 21 years common, everyday meanings arise in learning situations and cause difficulties in conceptual learning. "Children's science" may thus be a subset of "lay science".

"Lay science" and "children's science" although represented by differences in conceptual understanding, also represent differences in cognitive behaviour. "Lay science" differs from "scientist's science"
in two other ways. Individuals who exhibit "children's science" have difficulty with abstract reasoning and are interested in a particular explanations for specific events (Osborne, Bell and Gilbert, 1983).

6.5 Conceptual Exchange

According to Piagetian theories, "intellectual development" is the "process whereby individuals develop more powerful (general) executive schemes" (Gold, 1981). An important part of intellectual development is the acquisition of more general concepts which are capable of explaining a wider range of experiences than specific concepts. The nature of concepts may have to be changed, for example from those of "lay science" to those of "scientist's science". Misconceptions (rather than alternative conceptions) may have to be discarded for valid conceptions. This change of conceptual belief has been described as "conceptual exchange" (Hewson, 1980).

Conceptual exchange can be found, for example, when observations made by an individual cannot be explained by their present conceptual understanding or hypotheses, or, when it is apparent from a conversation, say with a teacher, that there is a conflict in beliefs. In Piagetian terms, the resolution of this cognitive conflict is known as "equilibration". Equilibration consists of looking for new relevant information, acting on this information and stopping when the original task requirements are met by the solution most consistent with the schemes activated (Gold, 1981).
A concept which replaces a previously held one must explain both the set of experiences which initiated the cognitive conflict, and the set of experiences which had been adequately explained by the previously held concept.

A similarity between Constructivist Epistemology and Peirce's Theory of Abduction is seen in Hewson's Model of Conceptual Exchange.

Hewson's model (Hewson, 1980) for conceptual exchange includes four conditions which are usually met before a concept is exchanged. The process of exchange is initiated by a feeling of dissatisfaction for the existing concept (condition 1). The new concept must be formed (although the process of concept formation does not form part of Hewson's model). The new, replacement concept is then judged as being intelligible (condition 2), plausible (condition 3) and more fruitful (condition 4) than the initial concept, that is the new concept should be capable of solving more problems than the initial concept.

(1) Dissatisfaction with a concept or hypothesis is said to occur when the existing concept is unable to explain new experiential data or new knowledge. The anomaly the person experiences is consistent with Peirce's notion of "surprising data".

(2) The second necessary condition is that the new hypothesis should be intelligible. Hewson sees the new concept being intelligible only if it is internally consistent, but not necessarily consistent with other knowledge. Peirce's pragmatic theory insists that only those hypotheses that are meaningful (in that they are verifiable) are reasonable hypotheses.
(3) Hewson's notion of plausibility corresponds to Peirce's notion of "intrinsic value" of a concept. Hewson's model requires a new concept to be consistent with the person's other knowledge. It is necessary to say a concept is true. To be able to say a concept is true, one must be able to understand it. Peirce says that a concept has intrinsic value if a person expects that hypothesis to be true.

(4) Finally, Hewson's model requires that the new concept to be fruitful. If the new concept explains not only the old data, but also the surprising data then that concept should be seen as fruitful. Here we can include Peirce's notion of "simplicity" which is included in the economical factor of "intrinsic value". Peirce believes that before a complicated hypothesis is tried, the person should make sure that no simplification of it would explain the facts equally as well. Hewson's notion of fruitfulness includes elements of elegance, parsimony, and economy. The distinction according to Peirce's model between conditions 3 and 4 is a hazy one, and can only be clarified by using Hewson's terms. The notion of fruitfulness implies that a new concept will only replace another if there is an intrinsic motivation to do so.

It has been reported (Osborne, Bell and Gilbert, 1983; Pickering and Monts, 1982) that children are sometimes capable of resisting influencing factors which could result in a change of their understanding of scientific concepts. Osborne, Bell and Gilbert provide five alternative ways in which the information presented by a teaching episode can be treated by a student. The information can be:
a) rejected;
b) misinterpreted to fit in with, or even support present views;
c) accepted, but in isolation from present views;
d) accepted but leads to confusion;
e) accepted and forms a coherent view of the world.

I have attempted to show that there are various models of concept formation and attainment, and that recent constructivist theories recognise the individuality of the nature of learning. It is my belief that each person constructs their own and individual "world" of concepts. Concepts, however, should be regarded as hypotheses which exhibit a dynamic nature in that they can be exchanged whenever the person believes that the relationship of experiential data with the rest of their body of knowledge so requires.

I have also tried to show that the dichotomy of opinion as to whether reasoning is inductive or deductive in nature can be regarded as a false dichotomy. In its place I have substituted Peirce's Pragmatic Theory of Retroduction, or Abduction, which entails not only inductivism and deductivism, but also entails a theory for the creation of hypotheses, or concepts, which precedes both of these processes. This theory, I believe has much in common with the Kellyian notion of the personal construction of knowledge and of "Man the Scientist".

In the remainder of this chapter I want to look at a number of ideas concerning the structure and representation of knowledge.
In Chapter One I looked at various theories of cognitive structure, especially those of Ausubel and Gagné, and various theories of cognitive style and strategy, especially those of Pask and Marton. In positing that if a person can have a strategy and preferred style for acquiring knowledge, it is not unreasonable to assume also that knowledge is structured in the mind.

In cognitive science and artificial intelligence studies, a lot of emphasis has been placed on how knowledge and skills are structured within the human brain. This interest in the structure of knowledge has developed from studies in what has been called "productive learning". In "productive learning", learning is seen to occur more readily when it is presented in a structured manner, such as by autoinstructional devices and their component learning programs.

Various theories concerning the nature of cognitive structure have been put forward. Piaget (1968), for example, sees a structure as a system of laws and their subordinate elements. He does not see a structure as being just a collection of elements and their properties, which, apparently, are the very "structures" proposed by workers such as Gagné and Ausubel. It is only more recently that cognitive structures have been developed which not only include propositional knowledge but also include the rules and principles relating propositions. This latter type of cognitive structure is more of a system representing knowledge and the way that it is structured by individuals in that relationships and the relative strength of these relationships can be shown, and therefore that meaning can be sought for some of these structures.
Schemes such as those of Gagné and Ausubel for structuring knowledge have mainly been used in the design of curriculum and lesson material. Evidence has been produced that knowledge could be structured hierarchically in the human brain (for example, Shavelson, 1972; Preece, 1976). By linking propositional statements associated with a hierarchy of skills, Baird and White (1982) produced a cognitive map which they believe to be consistent with the information that is stored in memory. Such a cognitive map shows the developmental relationship of various topics and subtopics, and is the structure which one would expect an expert to produce in an instructional setting.

West, Fensham and Garrard (1982) have attempted to develop methods for "eliciting, recording and transforming both the elements of cognitive structure and their organisation, in order to produce a representation of the cognitive structure of individual learners." These representations of cognitive structure are hierarchically arranged maps where the nodes, representing major propositions, are connected by "relationship" lines. The maps are produced by eliciting definitions of the various concepts and then obtaining a rating of the degree of relationship between the various pairs of propositional statements. Diekhoff and Diekhoff (1982) see the interrelationship of concepts in a topic area as "structural knowledge". They have produced their cognitive maps by a principal components analysis of numerical judgements of the strength of relationships.
The elicitation method for determining cognitive structure would seem to create relationships for a person to either knock down or support. It could lead to relationships being created. Students could say, "I didn't think of that before. Yes they are related!". This could easily account for the high number of "Ah Ah!" situations which were reported by West, Fensham, and Garrard (1982), and which led them to think that it could be a potential learning aid. The reason for using this method of elicitation was based on the authors' desire to "explore the possibility of summarising individuals' cognitive structures on some general dimensions." The use of an "intended cognitive structure" provides a framework. 'It is an expert's cognitive structure rather than that of a student.

Although evidence may exist which shows that knowledge is structured in the human brain, Cotton et al (1977) and Pask (1969) have cast some doubt as to whether all knowledge is so structured. Cotton et al believe that both motor and intellectual skills may simply transfer to another task rather than simply being prerequisite to it as in a Gagné-type hierarchy. Pask says that students demonstrate an unstructured body of knowledge when they are unable to say how they learn it. However, Pask believes that few areas of knowledge or skills are actually unstructured in the mind.

It is in the area of artificial intelligence that various structures have been developed, widely used, and proposed as being similar, at least functionally, to those structures in the human brain. Goldstein and Papert (1977) have described the essential concern of artificial intelligence as "the necessity to construct frameworks in which all the diverse kinds of knowledge can successfully interact in order to allow
the complete comprehension process to take place." Norman, Gentner and Stevens (1976) believe that learning is organised around "small, simple schemata that can be applied to situations wherever deemed appropriate." The conceptual structures are applied, by analogy, to a new situation or area of knowledge.

Workers in artificial intelligence have used a number of different structural forms for knowledge in their studies. Anderson and Bower (1973) used propositional trees in their computer simulation of memory, HAM (Human Associative Memory). Propositional trees, although suitable for describing conceptual understanding of small bodies of knowledge, are unsuitable for representing large bodies of knowledge. If these propositional trees are used to describe a large body of knowledge with all the possible interrelationships that exist, they would be extremely large and cumbersome. Thus, it is doubtful whether such structures would be found organizing a body of knowledge in the human brain.

Greeno (1973), although believing that cognitive trees are constructed in the learner's working memory, also believes that these structures are modified by information retrieved from semantic memory into relational networks. Network structures are probably more meaningful than other methods for representing bodies of knowledge. Norman (1973) in his "semantic networks" places concepts and events at the nodes of the network, and connects these nodes using directed, labelled relations to provide a meaning structure. Over a period of time, Norman's semantic networks have evolved into "deeper, more conceptually based representations". But Norman regards these structures as being too static, that is, they have not become dynamic structures. To
become dynamic structures, Norman believes that actions, like events, could be stored in memory in a similar way to that used for storing concepts.

Mitchell (1982) regards his network structures, which are similar to those of Norman, as being flexible in that any of the topics could be regarded as being hierarchically superordinate, with all other topics being subordinate to it. Unlike the structures I have already described, Mitchell believes that cognitive structures should be imagined as a fish net where the knots represent topics. Mitchell also believes that conceptual knowledge should be looked at using a systems analysis approach where the thinking is expansionistic. The system under consideration should be explained in terms of its function in the larger system of which it is part. It is not possible to properly decompose a system into its components. Hence Mitchell's views are similar to those of Norman:

"Learning involves the acquisition of new cognitive structures built upon old, previously acquired structures."
(Norman, Gentner, Stevens, 1976)

Rather than producing maps showing the relationship of a collection of isolated facts, Clement (1979) has produced maps of conceptions which show the actions leading to a result expectation. These maps are networks of action-oriented conceptions. They are detailed descriptions of an expert's knowledge structures.

Another model—which attempts to show a structure changing with time is that produced by Head and Sutton (1981) which emphasises the growth of many discrete parts forming a mosaic.
Corte (1980) has a typical information-processing approach in that cognitive activities are analysed and represented in terms of successive events that take place in the problem-solver. This type of study results in the production of flow-charts.

Concepts, if they are indeed structured in the mind, are not always clearly structured. Students have difficulties associated with "difficult" concepts. Okuda et al (1978) and Goguen (1974) have stated that because of difficulties associated with the representation of certain events, for example, in making decisions in the real world, concepts should be regarded as fuzzy events and represented as fuzzy sets.

Goguen sees the concepts as being hierarchically structured in the form of a tree. However, unlike previous tree structures that I have described, each conception is not seen as containing definite subconcepts. There is a probability that a concept contains certain subconcepts. This probability of a concept containing certain subconcepts is the "fuzzy" nature of the concept. The hierarchical fuzzy-set specifies an algorithm which can be used to compute the degree to which the concept holds in the state of the world.
6.7 Representations of the Structure of Knowledge - A Pedagogic Aid?

In constructing representations of the structure of a body of knowledge, it could be said that one is attempting to achieve one or more of three objectives, namely:

(i) Highlighting student conceptions, whether they be valid conceptions, alternative conceptions, or misconceptions.

(ii) The design of subject and curriculum material.

(iii) Helping students to learn (about learning).

Wildman (1981) sees learning as a generative process where meaning and comprehension must be constructed by individual learners.

If representations of cognitive structure are being used in the design of instructional packages, in showing conceptual relationships to students, in highlighting student misconceptions, then certain questions must be asked. Are they "true" representations of cognitive structure? Do they need to be true representations, or merely functionally adequate?

Shavelson (1972), whilst looking at Gagné-types of structure, has shown that the cognitive structure corresponds more closely to the content structure at the end of instruction than at the beginning. Preece (1976) has also shown that the cognitive structure of mechanical concepts for those students "knowledgeable in physics" is quite similar to the organisation of concepts in a learning hierarchy. But how much are these results due to a student's realisation of the hierarchical presentation of subject material? Ford (1980) believes that it is not likely that information is represented in the learner's mind in the same way as it is presented in the written or spoken form. It would
thus be necessary for some transformation of the information to take place, and that the presentation of a hierarchy is less likely to be the reason for Shavelson's and Preece's results.

Propositional trees and learning hierarchies have received much support. Why are network structures, for example, less popular, especially for those concerned with cognitive science, information-processing and programmed learning/computer assisted instruction? It could be because hierarchies and tree structures are relatively easy to produce and understand, and as Goguen (1974) says:

"From a computer science point of view, the tree representation is very convenient, but nets (or graphs) of concepts representing more complex interactions among components might be more appropriate though less efficiently implemented."

To consider whether a particular representation is a "true" representation of an individual's cognitive structure can be an unnecessary waste of time, especially when considering the presentation of subject material. If a structure can provide information which can be used in various teaching and learning activities, or to follow what is happening during the learning process in an adequate way, then that structure has fulfilled a valuable function and is acceptable as such.

Network structures which include relationships between concepts, rules and axioms which an individual uses in a particular context, will probably allow more meaningful findings to be made than propositional trees or hierarchy structures. Network structures, although essentially non-hierarchical, can be used to obtain hierarchical structures if it is so desired. Mitchell (1982) points out that it is possible to produce a number of different hierarchical structures depending upon a student's original conceptual base when they arrive at
the learning situation. By taking the desired superordinate conceptual node and "shaking" the net it is possible to produce the appearance of a hierarchy. This means, of course, that in a network structure there are a number of different routes through the subject material depending on the individual's prior knowledge and interests. This Mitchell calls a reticulated curriculum.

The importance of recognising individual constructions of knowledge is becoming increasingly popular as, for example, in constructive alternativism (Pope and Gilbert, 1983). Norman (1973) appreciates the importance of recognising students' network representations and tailoring instruction to the needs of the student. However, unlike Mitchell, Norman's instructional strategy is that of first constructing a support web structure, what may well be called an Ausubelian "advance organiser", and then progressively filling in the details. These are, therefore, two possible different strategies - a linear approach and a web approach. However, as Wildman (1981) says:

"Materials should be constructed so as to lead students through a constructed process whereby the essential features or structure is prominently displayed and subsequently elaborated with detail."

The process which teachers and educationalists are concerned with is that of easing the student's path to the acquisition of clear, detailed conceptual structures. How do computers do this and yet comply with the constructivist's notion of the individuality of the learner and their needs?

The function of an instructional model for Laubsch (1975) is to search the computer's semantic net, retrieve the frames to be taught, match the prerequisites of these frames with the student's prior knowledge
and interpret user queries and answers as updates of the instructional model.

Goldstein (1979) uses a model which is one of "rule-structured" knowledge. Her idea uses a graph structure whose nodes represent rules, and whose links represent various evolutionary relationships such as generalised correction and refinement. Goldstein is working within a learner-based paradigm rather than within an expert-based paradigm.

Expert-based CAI allows a student to explore a problem in his own fashion. However, the tutor has no guidance with respect to whether discussion of a given skill is premature in the context of those skills the student has already acquired.

Goldstein's genetic graph is an attempt at addressing this limitation. Knowing the knowledge that a student has, whether that knowledge is used using the CAI program, and knowing whether a particular strategy for providing explanations is consistent in increasing a student's knowledge, it is possible to use this model of the student to personalise the choice of explanation strategy. The student's knowledge is described in terms of the nodes of the graph, his learning behaviour in terms of the links, his progress in terms of the paths in the graph.

The mapping of cognitive structures and their subsequent use an aid to learning is in its infancy. Only by using models which are learner-based rather than expert- or script-based will a sufficient degree of flexibility and "realism" (for the student) be brought about.
Chapter 7

The Development of Concept Maps and Hierarchical Structures
as Techniques for Describing Learning

7.1 Introduction

In this chapter, I intend to describe how I have used various forms of concept map and hierarchical structures as a means of describing the learning process as promoted by the POND programs.

Concept maps attempt to illustrate the interrelationship of concepts. In these studies, I have tended to restrict their use to being representations of learning as exhibited by individuals rather than by groups of students. I had hoped that by determining concept acquisition and the relationships that concepts have in a student's mind, I might be able to explain some of the aspects of the learning process relevant to CAL.

Hierarchical structures attempt to show common patterns of conceptual learning. If such common patterns exist then use might be made of them in the design of CAL programs to improve the efficiency of learning by encouraging the acquisition of concepts according to this pattern.
CAL software may be structured so that concepts are presented to students in a hierarchical manner. In the POND programs, because of their modal nature, it might be said that students can partly assemble their own hierarchy of concepts by choosing a different order of program modes.

CAL software can be designed to impose a strict hierarchy (as did the programs used in "teaching machines" for example) on its users, or it can be designed so as to allow users of the program to take from it concepts in an order that is more natural, or meaningful, to that particular student.

To be assured that the design of a CAL program, with respect to the nature of the presentation of concepts, is educationally satisfactory, two questions need to be answered:

a) Do individuals have preferences for the order in which concepts are presented by software or is there some alternative (for example a common hierarchical network structure)?

b) Does learning take place more efficiently if a body of knowledge is presented in a hierarchical manner or when the personal choice of presentation and acquisition of concepts is encouraged?

These studies attempt to investigate these problems. This area of study involves many difficulties, not least of which is the problem of how to determine whether a concept has been learnt.
The results I shall present will demonstrate many of the difficulties that are encountered, rather than proving or disproving whether learning is hierarchical, or whether CAL programs should or should not encourage hierarchical learning of concepts.

7.2 Concept Maps

7.2.1 The Development of Concept Maps for Students using the POND Programs

The structure of concept maps in these studies went through a number of developmental stages to resolve various problems. These problems and difficulties in how the maps should be presented have not been resolved. Improvements were made and, indeed, this dilemma led me to develop an alternative method for illustrating the learning process (the Interaction Model - chapter 8).

I initially approached the problem of producing a concept map (figure 7.1) which I believed showed the concepts which the authors of the package notes (Tranter and Leveridge, 1978) believed should be acquired by using POND-2 and the ways in which they are interrelated. West, Garrard and Fensham (1982) have called this type of concept map "intended cognitions", the public knowledge that the students are expected to acquire by attending a particular educational course. It is the minimum information which students are expected to acquire and relate to relevant, previously taught bodies of public knowledge.
In the central part of the map shown in figure 7.1 are the concepts immediately related to the concept "food pyramid". To the left of the central concepts are those concerned with the effect of pollution on the ecosystem; to the right are those concerned with the effect of fishing on the ecosystem. All the concepts which I believe are related are connected by lines.

It is important to note that this map does not show any preconceived idea as to the direction of concept acquisition. It allows for both the general-to-specific and specific-to-general directions, or a combination of both.

This map I called a "master" concept map. I used it to look at the way by which the students who had used POND-2 built their individual conceptual structures.
Figure 7.1 A "master concept map" for POND-2

- Pollutant may act as a nutrient for plankton
- Algal bloom leads to anaerobic conditions
- Anaerobic conditions kills fish and herbivores
- Pollutant affects ecosystem
- Pollution may kill all organisms
- Algal 'bloom' may develop
- All communities depend on sun
- Plankton are primary colonisers
- Plankton can exist without fish and herbivores
- Herbivores depend on plankton
- Herbivores "follow" phytoplankton
- Fish "follow" herbivores
- Fish dependent on herbivores
- Size of population is interdependent
- Populations are interdependent
- Equilibrium can be upset by changes
- Equilibrium
- Weather affects ecosystem
- Cyclic changes in size of populations
- Fishing affects ecosystem
- Man fishing is a fourth trophic level in ecosystem
- High fishing rate makes fish become extinct
- Close season is time when no fishing
- Optimum fishing rate is twice a month
- Fish breeding season is March to May
- Close season should include March to May

Numbers = frequency of concept & relationship demonstration
(N=9)
The acquisition of a concept by a student usually requires several cognitive activities. For example, it may require the recall of previously acquired knowledge, it will require the "translation" of the numerical data output by the program, and then perhaps "interpretative" activities to show cause and effect. The combination of activities can be seen in the following extract of a transcript of my observations of a student (PN) using POND-2:

"...in phytoplankton and herbivores there is a relationship\(^1\), the numbers of phytoplankton are increasing from January to April, the numbers of herbivores also increase, and from April to June, the numbers of phytoplankton decrease, followed by a decrease in herbivores."

The student had translated the numerical data (2) and recognised that the herbivores "follow" the phytoplankton, and hence a relationship between the two populations exist (1). Individual concept maps were constructed for the nine students who used POND-2 were constructed by examining the observation protocol sheets and the interview transcripts.

During the interview, one student (TS) said:

"In a hot season the plants, well the phytoplankton, increase in numbers and so do the herbivores and hence the fish because they all feed off each other."

From this statement the following concepts can be recognised immediately:
(i) a hot season increases phytoplankton numbers,
(ii) herbivore numbers are dependent on phytoplankton numbers,
(iii) fish numbers are dependent on herbivore numbers.

At the time of using these maps, I believed that I could also say that
the student believed that:

(iv) weather affects the ecosystem,
(v) all populations are dependent on the sun,
(vi) the size of any population is dependent on the size of other
    populations.

These more general deductions (iv – vi) were made because the whole
statement was concerned with weather (hot season); because the student
was describing population changes as a result of the sun's activity
(heat); and because the three population changes were interrelated by
the words "...and so do the herbivores" and "hence the fish".

Figure 7.2 shows the part of the concept map which was completed from
this student's statement. All of the concepts were linked because all
of the concepts were made explicit in one statement and were thus
related.
Sometimes relationships were shown on the student maps which I had not thought relevant and thus had not included on the master map.

Figure 7.1, the master concept map, shows the frequency of demonstration of concepts and relationship between concepts. From this it is apparent that most (8 out of 9) students saw the way in which the fish, herbivores, and phytoplankton populations are interdependent. In other words, of the nine students who used POND-2, eight had shown an appreciation of the superordinate concept "food
"pyramid". The further the other concepts were from the central concept, the less frequently they were demonstrated.

Having produced these individual student concept maps I felt that the various concepts could be arranged in a more meaningful way. Such a way would illustrate, at least to some extent, how the students learn using a POND program.

I developed various forms of maps which in addition to the concepts related to the superordinate concept "food pyramid", also included the observations that a student should make to realise these concepts. Various methods of development of maps were used. Various forms of map were produced from semantic networks, webs and meshes to the more hierarchically arranged maps. However, I felt dissatisfied with the amount of information that these maps could convey. They did not represent the dynamic nature of the learning process.

Some of the difficulties I had with these maps may have been because some aspects of the interaction between the student and computer program were not included on the maps. That is to say, the maps did not relate to the learning process that occurred, but just to the "intended pedagogic process".

Figure 7.3 shows the concept map which I produced as a first attempt to illustrate the whole learning situation. This map is based on the realisation that students appear to use a CAL program in a series of cognitive activities which can be very simply illustrated as:
Such a series of activities is shown in this concept map (figure 7.3). The actions are placed on the base-line of the map, the observations on the next line, and the various concepts are placed above. The different activities are illustrated by various symbols together with codes which describe the exact nature of the activity. Although the codes are not important here to understand how the map attempts to diagramatise the whole learning situation, the symbols are
(section 7.2.1)

represents an observation

represents an INPUT action

represents a hypothesis put forward

represents a deduction

represents a fact recalled from memory

---

can be taken to mean "related to"

---

can be taken to mean "leads to"
Example of a master concept map for POND-2
The students' maps were constructed from the students' protocol sheets and the interview transcripts. Figure 7.4 shows a typical student's concept map obtained by this method.

Although I felt that this form of map was more successful in showing an element of the dynamic nature of the learning process, it was still not complete. More detail was required of the way the students use CAL programs. More detail of the actions (the INPUT values) were thus included. Because of the limited space within the INPUT symbol, the INPUT values were given in a general way. For example:

2D = Chose 0 herbivores
2E = Chose 1 to 25 herbivores
2F = Chose 26 to 50 herbivores

This facilitated a greater understanding of why, for example, observations were made. I also increased the number of relevant observations on my master map which I thought to be important in the development of a complete conceptual structure. For student maps I included all observations made. In addition to the greater detail of the INPUT values and observations included on the map, I decided that it would be better to group all observations, deductions etc. leading to the formation of a particular concept.
Figure 7.4  Example of a concept map resulting from a student's use of POND-2
The student maps produced by this method thus included all observations made, and whether or not they apparently led or did not lead to the formation of a concept. The record provided by a student's concept map might thus show that a particular student was capable of observing a large number of events, but not so capable of producing concepts from those observations.

In producing concept maps for the students using this method, I decided that two more modifications were necessary to make the maps more complete. The first of these was the inclusion of concepts which had not been made explicit by the students. The nature of these concepts being indicated by various observational statements. For example, in the statement:

"The herbivores are increasing because there are not so many fish around."

The student has made here two observation statements: the herbivore numbers were increasing; the number of fish had decreased. The two observations have been linked by the student with the word "because" which implies that the student had a notion of how the fish affect the herbivores. This concept would probably include an idea that the herbivores were predated upon by the fish, but without supporting evidence such a supposition as to the nature of the concept should not be made and included on a student's map. Instead, I decided to merely indicate that a concept of unknown identity existed with the symbol $\triangle U$. If I could make an "educated" guess at the nature of the concept, I include the code number of the appropriate concept, for example $\triangle U3$. The statement above made by the student would thus be represented:
The second modification which I felt was necessary to make was the inclusion of misconceptions or "alternative conceptions", shown as $M_{i}$, where 'M' indicates a misconception, and the number is a code specifically referred to on the protocol sheets. These misconceptions are just as important as the conceptions which an expert would regard as being valid in that situation. Figure 7.5 shows the concept map for the same student as the map shown in figure 7.4, but produced according to the methodology just described.
Figure 7.5 A Student's Concept Map
7.2.2 The Success of Concept Maps in the Analysis of Chronological Episodes in the Learning Process

The concept maps produced by this last methodology were found inadequate for a number of reasons. In some cases they are extremely complex and thus difficult to interpret. I felt that even with all the detail I had included they did not represent what I thought had been happening in the program runs. Neither did they contain all the information that I felt should be included, but to include more would increase the complexity of the maps beyond all understanding. Of course, it could be argued that these maps represent the sort of conceptual complexity that one would expect for such a body of knowledge.

These maps represent a summary of the whole learning situation. One great inadequacy of these maps is that the routes of conceptual development appeared on the maps which were the result of constructing the map and not a method of conceptual development observed to take place during learning. In other words, the maps were ambiguous and deceptive.

Glanville (1981) has found the same sort of difficulty with his construct heterarchies. He says:

"This ambiguity comes about after the event. That is to say, the ambiguity is not in the figure (or in the procedure for its production) as it is made, but it becomes apparent when the figure is looked at as a finished object, from an external point of view."

Glanville recommends that the cause of the ambiguity, the graphical representation, be overcome by representing the concepts (constructs) by its means of combination or interaction.
In conclusion, although these later concept maps were far more satisfactory than the earlier ones, I felt that concept maps were not the way to analyse the data I had available if I wanted to determine how students learn and how this is related to the characteristics of the CAL program structure.

The maps I produced were a final and total representation of what the students had achieved during their program run.

These maps, however, did not show the episodic, or chronological, development of the various concepts. I could not, for example, determine how a particular characteristic of a program affected the learning process. Also the maps were complex, difficult and ambiguous to interpret.
7.3 The Elucidation of Hierarchies

In these studies I initially identified eight concepts which I thought were the major concepts entailed within the concept "food pyramid", and which thus form an important part of the model used for the POND programs.

In the pre- and post-run interviews I asked the students to define the term "food pyramid" (see also 5.4). From these definitions, and other statements made during the interviews, it was possible to say whether a student possessed each of the eight concepts before and after their program run. Figure 7.6 shows the frequency by which each of the concepts were shown to be possessed by students in these studies. The level of frequency can be taken as an indication of subordinancy; the most subordinate concepts being most frequently demonstrated.
<table>
<thead>
<tr>
<th>Concept</th>
<th>-2 (9)</th>
<th>-QU (9)</th>
<th>-GAME (7)</th>
<th>-HELP (10)</th>
<th>TOTAL (35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. organisms interdependent.</td>
<td>3-7</td>
<td>3-6</td>
<td>0-6</td>
<td>1-10</td>
<td>7-29</td>
</tr>
<tr>
<td>b. interdependence shown by</td>
<td>3-6</td>
<td>2-5</td>
<td>3-6</td>
<td>4-9</td>
<td>12-26</td>
</tr>
<tr>
<td>feeding habits.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. herbivores feed on</td>
<td>5-7</td>
<td>4-7</td>
<td>5-7</td>
<td>6-5</td>
<td>20-26</td>
</tr>
<tr>
<td>phytoplankton.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. fish feed on herbivores.</td>
<td>5-8</td>
<td>4-7</td>
<td>4-7</td>
<td>6-7</td>
<td>19-29</td>
</tr>
<tr>
<td>e. number of plankton &gt; than</td>
<td>0-3</td>
<td>1-3</td>
<td>1-5</td>
<td>3-5</td>
<td>5-16</td>
</tr>
<tr>
<td>herbivores &gt; no. of fish.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f. phytoplankton</td>
<td>5-6</td>
<td>4-7</td>
<td>0-6</td>
<td>2-5</td>
<td>11-24</td>
</tr>
<tr>
<td>photosynthesise.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. all populations depend on</td>
<td>0-2</td>
<td>0-0</td>
<td>1-2</td>
<td>1-3</td>
<td>2-7</td>
</tr>
<tr>
<td>the sun.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. phytoplankton numbers</td>
<td>0-1</td>
<td>0-0</td>
<td>0-1</td>
<td>0-0</td>
<td>0-2</td>
</tr>
<tr>
<td>governed by environment.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(The above figures (x-y) indicate the number of students who showed possession before (x) and after (y) their program run).

Figure 7.6 Frequency of Concept Possession by Students using the POND Programs
In the hierarchy there is a distinct possibility of concept "islands" (Goldstein, 1979) being present. Concept "islands" occur where there are two very similar concepts, for example "fish eat herbivores" and "herbivores eat phytoplankton". Two such groups of concepts could exist here, concepts (a) and (b) forming one such island, and concepts (c) and (d) forming another. In an attempt to determine the best linear order of concepts, that is the most appropriate linear hierarchy, a linear regression analysis of various orders for the concepts was performed, as shown in table 7.7.

<table>
<thead>
<tr>
<th>Arrangement number</th>
<th>Concept order</th>
<th>Linear regression coefficient, r</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>d c f a b e g h</td>
<td>-0.941</td>
</tr>
<tr>
<td>2</td>
<td>c/d a/b f e g h</td>
<td>-0.962</td>
</tr>
<tr>
<td>3</td>
<td>c/d f a/b e g h</td>
<td>-0.958</td>
</tr>
<tr>
<td>4</td>
<td>d c a/b f e g h</td>
<td>-0.946</td>
</tr>
<tr>
<td>5</td>
<td>c/d a b f e g h</td>
<td>-0.940</td>
</tr>
</tbody>
</table>

Figure 7.7 Linear Regression Coefficients of a Number of Possible Linear Concept Hierarchies for POND-2, PONDQU and PONDGAME
The most likely hierarchy for POND-2, PONDQU and PONDGAME, from the linear regression coefficients given in figure 7.7 would appear to be:

```
( c d ) -- ( a b ) -- f -- e -- g -- h
```

In other words, the students firstly appreciate the feeding habits of the fish and herbivores; then appreciate that the pond organisms are interdependent; then work out that the phytoplankton must be photosynthetic; then comes an appreciation of the relative sizes of the populations, a deduction that all populations are dependent on the sun and that the plankton numbers are dependent on the sun.

The hierarchy appears to be somewhat different for POND2HELP where the hierarchy appears to have the order of the first two concept islands reversed:

```
( a b ) -- ( c d ) -- f -- e -- g -- h
```

The order has a linear regression coefficient of \(-0.938\). A higher linear regression coefficient (\(-0.964\)) can be obtained by separating the concepts in the two islands thus:

```
a -- b -- d -- c -- f -- e -- g -- h
```

The change in hierarchical acquisition of concepts encouraged by the structure of this program, probably largely related to the questions posed and to a lesser extent to the help provided.
Figure 3.4 showed the hierarchy of concepts that I decided to present in POND2HELP. At the start of the hierarchy was the concept of the relative sizes of the three populations in the pond, followed by the concept that the pond organisms are interdependent, and then by the specific concepts describing how the pond organisms are interdependent, and then by the specific concepts describing how the organisms are interdependent ("fish feed on herbivores" and "herbivores feed on phytoplankton").

By presenting the concept "that organisms in an ecosystem are interdependent" in the program as a subordinate concept seems to have encouraged it to be demonstrated more frequently (and thus be more subordinate) by the students using POND2HELP than by those students using the other three POND programs.

A conceptual hierarchy related to a learning package which has been obtained from interview data must be somewhat questionable. A hierarchy derived from data obtained from observation protocols should be closer to the real situation. Even this method must be open to some question as one cannot be certain that the individual being studied is revealing all that they see and find out about the simulation model, nor is any statement made indicating a perception or conception made at the actual time that the perception or conception was made.

In these studies various methods were used to derive hierarchical structures. Appendix 16 shows the order in which the students using the four POND programs demonstrated various concepts relevant to the
To unravel a branching, or tree, hierarchical structure from the order in which students appear to acquire concepts is extremely difficult; also, as I hope to show, the hierarchical structure obtained is open to some question.

The method described below initially provides a linear hierarchy from which a "tree" form can be derived:

Stage 1:
The observation protocols of the students' program runs and the supporting information from post-run interview data indicate the order in which students demonstrate (and thus acquire?) the various concepts.

Stage 2:
A table is prepared showing the frequency with which each concept precedes all other concepts demonstrated by each of the students using a POND program. For example, if a total of five relevant concepts are demonstrated by students using a program, then the table would consist of a 5 x 5 matrix thus:
On this table, the number of times each of the concepts precedes each of the other concepts is noted. Precedence need not be immediate precedence, but merely being demonstrated earlier than another concept. For example, if a student demonstrates the following order of concept acquisition:

```
3, 2, 1, 4, 5
```

where concept 3 precedes concepts 2, 1, 4 and 5, this would be noted on the table as:

```
1 2 3 4 5
1
2
3 1 1 1 1
4
5
```

This process is then repeated for the second concept, then for the third, fourth and so on. The resulting table would now have the following appearance:
This process is repeated for all of the students using a particular program so that a composite table is produced thus:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stage 3:
The number of times each concept precedes all other concepts is calculated by summing the values on each horizontal row of the table thus:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
The concepts with the highest summation value would be those which precede the other concepts most frequently, and thus which would be found earlier in a linear hierarchy. They would be the concepts which, for a particular group of students, precede the other concepts most frequently.

From the summation values, a hierarchical list, a linear hierarchy, of concepts can be produced. Those concepts having equal summation values are placed together in the hierarchy and thus shown to have equal precedence, as do, for example, concepts 2 and 3 in the following linear hierarchy prepared from the previous table:

\[
\begin{array}{cccc}
2 & 3 & 1 & 4 & 5 \\
\end{array}
\]

Stage 4:
From this linear hierarchy an attempt at producing a branching or "tree" hierarchy can be made. This hierarchy will have a number of levels. The base level initially consists of those concepts which have been shown NOT to precede any other concepts, that is those concepts which are only found at the end of the hierarchical list.
Stage 5:
The map is then built up by taking those concepts of the next lowest frequency and placing them on the next highest level of the map. If these concepts precede any of the concepts on the lowest level or at the same level, this is shown by an arrow connecting the two concepts, for example thus:

![Diagram]

This process is continued for concepts of all higher frequencies, all precedences to concepts on lower levels or the same level being shown by arrows. If, however, a particular concept precedes a concept say two levels below as well as another concept immediately below which itself precedes the same concept, the only an indirect precedence is shown. For example, if concept A precedes concepts B and C, and B precedes C; A is only shown to precede B, and B is shown to precede C.

Stage 6:
The result of stage 5 can be a complex diagram which has many arrows indicating relationships by precedence. This diagram may also show concepts on the same level although one may be preceded by several others, and another may not be preceded by any. The next stage is, therefore, to reconstruct the diagram so that the levels of the map start with those concepts which ONLY PRECEDE other concepts and are not preceded (these concepts can easily be recognised because they do not have arrows pointing towards them. These concepts can be regarded as those which are essential prerequisite concepts for a particular area of conceptual development. Those concepts which are immediately above
are then shown, the process being repeated until the lowest level concepts are reached. This reordering of the diagram usually means that those concepts which do not appear to precede any other concepts are found on different levels of the map.

Stage 7:
The relationships between pairs of concepts are now examined in more detail. If a concept on a higher level is found (from the precedence table created by stage 3) to precede a concept on the next lowest level fewer times than the lower level concept precedes the higher level concept, the two are interchanged. If, for example, concept A precedes concept B twice, and concept B precedes A four times, B is shown to precede A on the diagram.

Stage 8:
When concepts are interchanged as in stage 7, the concept placed at the higher level must be examined to see whether it precedes any concepts on the lower levels which have not yet been shown. New relationships might thus be shown, and stages 7 and 8 might have to be repeated several times until a constant diagram results.

Figure 7.8 shows the linear hierarchies obtained by carrying out stages 1 to 3 for each of the POND programs.
## Hierarchical Level POND Program

<table>
<thead>
<tr>
<th>Level</th>
<th>POND-2</th>
<th>PONDQU</th>
<th>PONDGAME</th>
<th>PONDHELP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>25</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>7</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>26</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>20</td>
<td>13,31</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>31</td>
<td>29</td>
<td>11,15,43</td>
<td>6,22,46</td>
</tr>
<tr>
<td>7</td>
<td>37</td>
<td>6,8,11</td>
<td>44,14,21,10</td>
<td>10,14,47,18</td>
</tr>
<tr>
<td>8</td>
<td>6,19,22</td>
<td>28</td>
<td></td>
<td>24</td>
</tr>
<tr>
<td>9</td>
<td>9,14</td>
<td>1,18,19,31</td>
<td></td>
<td>21,34</td>
</tr>
<tr>
<td>10</td>
<td>34</td>
<td>21,41</td>
<td></td>
<td>11,15,26</td>
</tr>
<tr>
<td>11</td>
<td>30,15</td>
<td>42,22,27,35,37</td>
<td></td>
<td>31,23,16</td>
</tr>
<tr>
<td>12</td>
<td>4,5</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>8,23,35,39</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>10,36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>11,16,32</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>38,24,40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(N.B. the numbers refer to particular concepts which are described in appendix 17)

Figure 7.8  Linear hierarchies of valid and invalid concepts demonstrated by the students using each of the POND programs
From figure 7.8 it can be seen that there is very little in common between each of the linear orders of concepts, except that concept 7 ("herbivores are dependent [feed on] phytoplankton") is the first in the order for three programs (POND-2, PONDGAME and POND2HELP). Concept 9 ("fish are dependent on [feed on] herbivores") is the first in the order for PONDQU, and second for PONDGAME and POND2HELP. Concept 20 ("weather affects the ecosystem") is the only other one which appears to be consistently early in the hierarchical order (third for POND-2, fourth for PONDGAME and POND2HELP, and fifth for PONDQU).

Using the method described here to determine a linear hierarchy demonstrated by a group of students during their use of a particular CAL program does presuppose that all the students acquire a particular group of related concepts in a similar order. If, however, concepts are acquired in different orders and arrangements depending on prior experiences, interests etc. (that is, there is a personal construction of knowledge) then one could expect a number of different orders to be shown. This would mean that the linear hierarchy obtained for a group of students would be a jumble of individual hierarchies with little consequent meaning.

The fact that concepts 7, 9 and 20 are noticeable in that they feature as relatively subordinate concepts for those using each of the POND programs would appear to indicate that they are subordinate concepts for most of the students in these studies. These concepts are the obvious and noticeable ones. There is an obvious seasonal variation of the three populations (concept 20). It becomes obvious that the organisms feed on each other and that fish feed on herbivores (concept 9) and herbivores feed on phytoplankton (concept 7) should become
obvious with perhaps some experimentation with, and observation of, the simulation model.

Of the 35 students participating in these studies, there was some area of commonality in the order in which concepts were demonstrated (acquired?). Figure 7.9 shows the frequency by which the initial valid concepts were demonstrated.

<table>
<thead>
<tr>
<th>Concept no.</th>
<th>1</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>3</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 7.9 Frequency by which concepts are demonstrated first during a student's program run using the POND programs.
From figure 7.9 it is obvious that of the total of 47 valid and invalid concepts demonstrated by students using the POND programs in these studies, six concepts (1, 7, 9, 11, 18 and 20) were demonstrated first by 25 students. This indicates that some kind of hierarchical acquisition of concepts is taking place, at least in the early stages of their use of a CAL program.

In addition to this finding that there is some similarity in the initial concepts demonstrated, it can be seen in appendix 16 that for those students demonstrating the same initial concept there is little in common in the order in which other concepts are demonstrated.

Concepts 7 and 9 are often demonstrated (acquired?) chronologically very close to one another. I have already said that these two concepts may be regarded as a concept "island"; once one is acquired then the other may also be acquired very soon afterwards.

It is probably therefore incorrect to say that the structure of a CAL program can force a hierarchical acquisition of concepts on to an individual. There may, however, be a slight influence, but one which has no great effect on learning.

If any of the POND programs were to encourage the acquisition of concepts according to a particular hierarchy then it would be PONDQU and/or POND2HELP. Both were designed to encourage the acquisition of concepts according to a certain hierarchy. PONDQU attempted to do this by posing questions which needed a correct answer before the student could progress on to experimenting further with the simulation
model. POND2HELP would only encourage a hierarchical acquisition of concepts if the students desired help in how they should use the program. Figure 7.10 shows that POND2HELP does not impose its hierarchy on to the students using the program.

<table>
<thead>
<tr>
<th>Concept no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>11</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>18</th>
<th>19</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position in provided hierarchy</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>12</td>
<td>13</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Position in hierarchy demonstrated</td>
<td>12</td>
<td>--</td>
<td>--</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>7</td>
<td>10</td>
<td>11</td>
<td>7</td>
<td>--</td>
<td>8</td>
<td>---</td>
</tr>
</tbody>
</table>

Figure 7.10 A comparison of a provided hierarchy with that exhibited by students using POND2HELP
Not one of the students using POND2HELP showed an order of concept acquisition that resembled in any way the hierarchy presented by that program. This program however was designed not to impose a hierarchical acquisition of concepts on its users since it was found with those students using PONDQU that this reduced the amount of experimentation exhibited. POND2HELP is able to offer help which is designed to be at a suitable level as determined by the answers provided to questions posed according to the stated hierarchy. Only if a student has formed concepts solely according to the advice given on request might s/he exhibit an order of concept acquisition similar to that used in designing the program.

PONDQU was designed so as to encourage the students to acquire the essential concepts as they progressed through each of the four modes of the program. The questions which required answers to be provided by the student through the keyboard, had to be eventually answered correctly before they could return to the simulation part of the program.

Students using PONDQU exhibited a range of modal orders. If the structure of the program were to influence the order in which the concepts are acquired, then it must be expected that one should find different orders of concept acquisition depending on the order in which the modes of the program are used.
<table>
<thead>
<tr>
<th>Modal order</th>
<th>Expected order</th>
<th>Obtained order</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 4 2 3</td>
<td>11 4 9 7 26 23 6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41 42</td>
</tr>
<tr>
<td></td>
<td>1 2 3 4</td>
<td>11 4 9 7 26 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 26 6 26 8 7 21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11 7 9 1 21 22</td>
</tr>
<tr>
<td></td>
<td>1 4 3</td>
<td>11 4 9 7 26 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 25 26 9 7 28 8 18 19 21</td>
</tr>
<tr>
<td></td>
<td>3 4 1 2</td>
<td>26 23 11 4 9 7 26 23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>2 4 1 3</td>
<td>9 7 6 26 23 11 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31 7 37</td>
</tr>
</tbody>
</table>

Figure 7.11  A comparison of expected and obtained concept orders for students using PONDQU
As with POND2HELP, there appears to be little evidence (figure 7.11) to show that the program structure is affecting in any marked way the order in which concepts are demonstrated during the use of the simulation.

Figures 7.12 to 7.15 show the branching hierarchies obtained by the method described here (stages 4 to 8) for each of the four POND programs. Although the concept maps for the four POND programs show some similarity and appear to show some understandable relationship between concepts, there are parts of each of the maps that do not appear to demonstrate interrelationships between concepts that one would normally expect to be directly related. For example, in the hierarchy for POND-2, the two concepts "pollution leads to a decline in fish numbers" and "primary producers trap solar energy" are related.

These linear and branching hierarchies are of intrinsic interest in that they probably demonstrate that:

individuals can vary considerably in the range of concepts that they demonstrate and the order in which they acquire them. However, they do not seem to be capable of extensive use in the evaluation and design of CAL programs.

These hierarchies have shown that the concepts of common subordinancy are those concerned with the direct interrelationship of the three trophic levels in the ecosystem, that is, which populations feed on each other. It appears that once these feeding relationships are sorted out, individuals can acquire concepts in a variety of orders as well as exhibiting the acquisition of different "spectra" of concepts.
Figure 7.12  Hierarchy of Concepts for students using POND-2

(for concept descriptions see Appendix 17)
Figure 7.13  Hierarchy of Concepts for students using PONDQU

[FOR CONCEPT DESCRIPTIONS SEE APPENDIX 17]
Figure 7.14  Hierarchy of Concepts for students using PONDGAME

(FOR CONCEPT DESCRIPTION SEE APPENDIX 17)
Figure 7.15  Hierarchy of Concepts for students using POND2HELP

(FOR CONCEPT DESCRIPTIONS SEE APPENDIX 17)
7.4 Concept Maps and Hierarchical Structures as an Evaluative Tool

The use of concept maps and hierarchical structures as an evaluative tool in these studies had little success. I had not designed the way in which I had observed students and later interviewed them to obtain specific information concerning how the concepts were hierarchically acquired and to determine their relationship with other concepts.

Some studies (for example, West, Fensham and Garrard [1982]; Diekhoff and Diekhoff [1982]) set out to determine the degree of interrelationship between concepts. This in itself can be a learning process for the student as indicated by the number of "Ah Ah!" situations that are quoted. The research question in describing the conceptual structure of a learner should be concerned with the conceptual links that a student uses, rather than one concerned with the links that can be initiated by the question posed by the researcher.

Concept formation and its accommodation into the existing conceptual structure should be followed by a close, clinical, detailed observation of learning under normal learning conditions. The dynamics of the process need to be described, the factors influencing the process are important. Students need to be encouraged to talk as they learn so that the researcher has the fullest information possible from which they can analyse the process and describe the factors interfering or influencing learning.
Some of the difficulties encountered in these studies may be related to this lack of suitable information. If I were to repeat this area of my studies I would certainly attempt to encourage all the participating students to "talk as they learn". I am uncertain how this encouragement would be provided to ensure the necessary "running commentary". Not all students feel able to do so. However, to prevent these people from participating would mean that only a partial picture could be obtained.

Both the concept maps and hierarchical structures obtained in the studies showed the personal nature of learning. Although learning appears to be a personal experience, these studies have shown that where a flexible programme of learning occurs, most people begin by acquiring somewhat similar concepts, by producing a similar "conceptual base". Once this base has been acquired, learning appears to take a number of paths depending very much on the individual.

There is very little evidence from these studies to show that program structure, such as the hierarchical presentation of concepts, will influence conceptual learning to any marked extent. Program structure, on the other hand, may be able to influence the cognitive processes and facilitate or inhibit conceptual learning. This is considered in the next chapter.
8.1 Introduction

In the last chapter I described how I attempted by using concept maps to demonstrate the way in which students acquire a particular body of knowledge. In terms of the ability of such a method for representing knowledge acquired by a dynamic process of a student interacting with a computer program, concept maps were found to be limiting. It is, for example, very difficult to include all the detailed information necessary to show how knowledge is constructed.

The Interaction Model attempts to overcome many of the difficulties encountered by using concept maps. Indeed, the Interaction Model developed as a direct result of that work. In developing different forms of concept map, I had attempted to illustrate the basic process of learning with the aid of a computer. This basic process of learning, what might be described as an episode or a learning event, is formed of three distinct stages (action, observation and conception) each one of which can lead to the next. Thus a learning episode, in terms of student cognitive activities, can be illustrated thus:

ACTION ————————► OBSERVATION ————————► CONCEPTION
8.2 **The Development of the Interaction Model**

The basic learning episode can be more fully described thus:

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
<th>OBSERVATIONS</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>action</td>
<td>of data</td>
<td>of simulation</td>
<td>of laws</td>
</tr>
<tr>
<td>by student</td>
<td>by the computer</td>
<td>model's behaviour</td>
<td>describing model</td>
</tr>
</tbody>
</table>

Here, I have included an additional stage to the learning episode, that of the OUTPUT of data. This stage is the visual stimulus for the learning process.

To use such a model to describe the learning process is unsatisfactory since it would produce an incomplete account. There are various intrinsic and extrinsic factors affecting various stages of the interaction process and which should, therefore, also be included in the model. These factors, for example, include the structure of the CAL program, the student's prior knowledge, experiences, interests, and preferred strategic style. The Interaction Model developed as part of these studies thus includes not only the stages occurring during a learning episode, but also a realisation that the influence of extrinsic and intrinsic factors on the learning process.
The Student-CAL Interaction can be regarded as a continuous process (Kemmis, 1977a). However, it seems natural in describing the learning process to divide the "Student-CAL Interaction" process into a series of episodes. The INPUT of data would seem to be a natural starting point for an episode.

During one complete learning episode, seven important events can be distinguished.

**Event 1 INPUT of data** - This is the means by which the student communicates with the computer. It is the means by which a student replies to questions that the computer poses, and thus the way by which the parameter variables of the simulation model are varied by the student. The values of the parameter variables may be chosen by the student by guesswork, that is by what is often known as "button-pushing". However, one hopes that parameters would not be chosen in this way, but by the use of informed reasoning, so that, for example, hypotheses can be tested. The INPUT of data may, therefore,
arise from preconceptions that have been formed during earlier learning experiences.

**Event 2**  The Calculation - Following the INPUT of data for the appropriate parameter variables, the computer will perform calculations based upon them and the mathematical expression of the simulation model. These calculations usually result in the production of a unique set of data since random number generators are often included in the program statements of the mathematical formulae. These calculations, of course, occur within the "blackbox" of the computer. Often the students will have very little knowledge of this part of the interaction process. However, the students should come to understand the simulation model by observing the results of the calculations (the OUTPUT data).

**Event 3**  **OUTPUT of data** -- The data can be OUTPUT in a variety of forms, but it is usually in the form of a table, a graph, or perhaps a pictorial representation. The choice of output style may be left to the student (within limitations), but it may also be controlled by the program developer if s/he requires the students to use a particular graphical format. It may be that a particular form of output might be more desirable than another for the demonstration of certain relationships; it may be that the students are required to manipulate data obtained from a particular graphical format. The output of data by the computer should be so designed that it stimulates the students to look at it, to enable the students to understand the information being displayed and to produce the appropriate meaningful relationships from that data.
Event 4 PERCEPTION - The perception of OUTPUT data might be affected or influenced by a number of factors, such as the student's prior knowledge and experiences. This may limit what the student selects as important to observe. Perceptions might be affected by the strategy that the student uses to produce meaningful relationships.

Event 5 OBSERVATIONS - These are the statements made by a student following perception. The proportion of perceptions that are made explicit by a student in the form of observations will vary quite considerably between students. Thus, it is necessary to follow the student's program run with an interview where the researcher uses the stimulated recall technique. Hopefully, this will improve the knowledge that the researcher has of a student was seeing, and thinking, during various stages of the program run, in an attempt to increase the observation/perception ratio.

Event 6 CONCEPTION - This is the stage of the interaction process in which the "higher" cognitive activities are occurring within the "black-box" of the student's mind. One hopes that by using a CAL program, a student is producing meaningful relationships between the events that are being displayed by the computer and being perceived (?) by the student. The Interaction Model is an attempt to demonstrate the events leading to this stage in the learning process. CAL programs should be so structured so as to encourage the formation of accurate, valid perceptions and conceptions.
Event 7 The Concept - This is the statement made by the student making explicit the possession of a concept. As with the observations that the student makes, not all of the concepts that a student forms may be made explicit, but the student should be encouraged to make as many of them explicit as possible during the program run and during the following interview.

8.3 The Use of the Interaction Model to Analyse Student Learning Processes

8.3.1 Construction of Case-Studies for Student Program Runs

The Interaction Model is used mainly in the analysis of protocol sheets with the aid of retrospective information obtained during the interview. Detailed case-study notes are written for each student's program run. I adopt a common procedure for writing each case-study, namely:

(i) Using the information from the pre-program run interview, I try to ascertain and describe preconceptions a student has concerning the concepts contained within the simulation model.

(ii) Using the information on the protocol sheets of the actions and comments made by the student during their program run, and any supportive information obtained during the post-run interview, I describe, in detail, both verbally and diagrammatically (using the Interaction Model) the student's progress during the program run. The descriptions are, therefore, chronological, episodic representations of the learning processes demonstrated by the student. I also try to show the effect that a previous episode may have had on a current
episode, and thus demonstrate the continuous nature of the learning process.

(iii) Using the post-run interview data, I try to describe the net result, for each student, of using the program in terms of the factual knowledge that was acquired.

8.3.2 Descriptions of Cognitive Activities

Earlier (1.3) I reviewed various descriptions of the learning activities that occur whilst a student uses a CAL program. I have also stated that little is known of how these activities are initiated and influenced by the structure of the CAL program, nor has any real attempt been made to define in detail what these learning activities are.

Using the Interaction Model, some greater insight can be brought to bear on both of these apparent deficiencies. We can sometimes see how and why a learning episode occurs, and what the nature of this episode is in terms such as those used in Bloom's taxonomy (1956), Kemmis' typology (1977a) and Laurillard's learning activities (1978a).

During the work concerned with my pilot studies I produced a hierarchy of cognitive activities (2.5.6) based on those of Bloom (1956) which I thought would be suitable for describing the activities occurring during the Student-CAL Interaction. This hierarchy, consisting of twelve levels, proved to be more than sufficient to describe student activities whilst they used a CAL program. The number and nature of
activities seen as being of importance in these main studies were, therefore, altered as the following descriptions (a-m) show:

(a) **Strategic Decisions.** These strategic decisions are what I have previously called "actions". A strategic decision includes the INPUT of data, that is, a decision to set a parameter variable at a particular level. Strategic decisions also include other actions such as a decision to compare sets of data obtained at various times during a program run. This can be seen, for example, in the following diagrammatic representation of part of a student's (ST) program run (POND-2):
In this case, the student (SHI) wanted to see how the numbers of organisms had changed over a three year period. The availability of a hardcopy printout of the information that had been displayed on the screen often facilitates the comparison of a current set of data with previously displayed data.

(b) Translation. Translation is the basic form of comprehension. An observation statement is made by the student indicating that some of the data has been understood. Only those observations made explicit can be noted and recorded. A translation activity is the third stage of what I have called a basic learning episode in CAL:

```
INPUT1
OF
DATA
```

```
OUTPUT1
OF
DATA
```

```
OBSERVATION
1
```
(c) Basic Method of Concept Acquisition. This is a form of comprehension, it is interpretation of the data. This is the fourth stage of the basic learning episode. However, to form a concept, that is to display an understanding of the simulation model, it is usual for more than one observation to be required. Usually a minimum of two observations are required as can be seen in the following extract of a student's program run (ST: POND-2):

```
/Moderate POLLUTION IN JUNE

/INPUT

OUTPUT OF DATA

HERBIVORES INCREASE

PLANKTON INCREASE

HERBIVORES FEED ON PLANKTON
```
(d) Predictions (example 1 - extrapolation). This is the highest form of comprehension. Often a prediction is made following what appears to be one observation of a change in numbers, for example:

An extrapolation may be made after comparing sets of data:
(e) Selection of Appropriate Enquiry Skills when performing an experiment. In general terms this activity can be shown diagrammatically as:

A good example of one student (SH2: PONDQU) selecting the appropriate enquiry skill to set up an experiment to determine whether each of the three organisms (fish, herbivores, and phytoplankton) in the pond ecosystem can survive alone is shown below:
(f) Predictions (example 2 - theory laden). Here the student predicts the effect of the change of a factor on a situation based upon a previously acquired conception. It is possible that this type of activity is the first part of hypothesis testing. I see this type of activity consisting of the following sequence of events:

The following example which is a diagramatised extract of a student's (ST: POND-2) program run shows not only a typical example of this type of prediction, but also how the student has related an inappropriate concept, indeed a misconception in terms of the simulation model used in these programs, to the situation:
The student in this example has not realised the effect that pollution will have on the fish population. Instead, since there are "lots of plankton and herbivores" as a source of food, the fish shouldn't decline.
(g) Theory-laden Observations (example 1). This activity is a form of analysis in that it is hypothesis testing using experimental data. In some ways, as the name of the activity suggests, it is more than merely testing a hypothesis. By holding a particular conception, or theory, the student's perception can be affected, even to the point of the evidence being falsified. The sequence of events can be illustrated thus:

An extract of one student's program will illustrate such an event. The student (PS: POND-2) INPUTs 10 fishermen fishing twice a month with a close season between March and June. He made the following observations:

"The number of phytoplankton decreases when the number of fish decreases. Fishing definitely decreases the number of fish as well as the number of phytoplankton."
Having a conception that phytoplankton are proportional to the fish is supported by the observation 1 and statement 2 is merely a restatement of this belief. Statement 1 can be shown diagrammatically to develop thus:
(h) Theory-laden Observations (example 2). This is a form of hypothesis-testing which uses experimental data. The difference between this and example 1 of the same type of activity can be seen in the following diagram:
On making the first observation, a second observation is expected because of a previously held concept. This second observation is made since a concept is held which makes that second observation necessary according to the student's belief. This would thus provide the student with the evidence to support the hypothesis.

An example of this type of activity is shown in the next example. DW (POND-2) started fishing the pond, and observed:

"The number seem to decrease with fishing... Let me see what affect it has on the phytoplankton. The number of phytoplankton seems to be less during the fishing season... The number of herbivores seems to decrease somewhat, perhaps because the fish have gone. Fish excretory matter feeds the phytoplankton..."

A misconception (6) is evident in this quotation of the student's comments made during his program run. If we look at how this misconception developed, we can see that a decrease in the fish population (1) caused the student to re-examine the data (1) to see whether this change in population size had resulted in any change in the size of the phytoplankton population. I believe that the strategic decision (2) shows that the student must have already had some idea of a relationship between the organisms. It may have been a very vague or general notion such as:

(i) fishing affects the ecosystem, and/or
(ii) the sizes of the populations within an ecosystem are interdependent.

On re-examining the data, the student observed a decrease in the phytoplankton (3) and also a decrease in the herbivore population (4) which he associated with the decrease in the fish population (5). This sequence of events can be illustrated diagrammatically thus:
Input fishing variables → Output of data → FISH DECREASE → COMPARISON OF DATA → RE-EXAMINE THE DATA → PLANKTON DECREASE → HERBIVORES DECREASE → FISHING AFFECTS THE ECOSYSTEM & OR POPULATION SIZES ARE INTERDEPENDENT.
(i) Hypothesis-testing (example 1). This is similar to the previous two activities (g and h) but there is an explicit or implicit desire to test a hypothesis. This type of cognitive activity can be illustrated thus:
Good examples of this can be seen in the following illustrations:

(MISCONCEPTION)

- **WANT TO SEE IF TREND CONTINUES**
- **CONTINUE TO YEAR 2**

(MINIMUM FISH POPULATION IS 50)

- **OUTPUT OF DATA**
- **FISH DECREASE TO 50**
- **SEE IF HYPOTHESIS IS CONFIRMED**
- **NO FISH CAUGHT**
- **MINIMUM FISH POPULATION IS 50**

- **ECOSYSTEM WILL ALWAYS REACH A BALANCE EVEN IF FISHING RATE IS CHANGED**

(PS: POND-2)

(PS: POND-2)
(j) Hypothesis-testing (example 2). This learning activity I recognise as being of a higher cognitive level than the previous example. Here the student tests a hypothesis through experimentation. This can be illustrated in general terms thus:
An illustration of such a cognitive activity from a student's program run shows how many students attempt to set up the various parameters of the simulation model to test hypotheses that they have formed.
(k) **Hypothesis-testing (example 3).** In many respects this form of cognitive activity is very similar to the previous activity, but it is more complex and includes the test to confirm or refute the hypothesis (the inductive stage according to Peirce's notion of scientific methodology), as shown in the following illustration:
(1) Concept Acquisition by a Hierarchical Development. This activity involves the construction of new knowledge from previously held concepts. The following illustration will show one way by which this might take place:

Concept 3 is formed by relating concepts 1 and 2, both of which are prerequisite to it.

(m) Dialecticism. This is where an observation is questioned because it is inconsistent with the student's conceptual structure, it is a "surprising event". It is inconsistent with the laws and rules that the student has of the simulation model's behaviour. It may be an evaluation of the accuracy of the results obtained. The following diagrams illustrate part of a student's program run where laws and axioms held by the student which explain the behaviour of the
PLANKTON DECREASE/MODERATE POLLUTION IN JANUARY

PLANKTON DECREASE

NO HIGHER ANIMALS

PLANKTON EATEN BY HIGHER ANIMALS

THEORY QUESTIONED

PLANTON INCREASE LEADS TO HERBIVORE INCREASE LEADS TO FISH INCREASE

OUTPUT OF DATA

HERBIVORES INCREASE

PLANKTON DECREASE

RULE QUESTIONED

(PN:PONDQ)

(SA:PONDQU)
8.3.3 Analysis of Program Runs in terms of the Cognitive Activities Demonstrated by the Students

Having produced a set of case-study notes, including illustrations of the program run drawn using the Interaction Model as a basis, facilitates the distinction of the various cognitive activities as described previously (8.3.2). It is thus possible to construct a profile of the range and frequency of cognitive activities for each of the students using a particular POND program. In addition to this information, I thought it valuable to record:

i. The number of sets of data a student INPUTs during a program run,

ii. The number of relevant concepts a student possesses before the start of the program run, as determined by a pre-run interview,

iii. The student's "invariability factor". This invariability factor" represents the order in which students use the various modes of a program. Obviously, this does not apply to PONDGAME where various modes are not available. In the three programs where four different modes of the program were available to the student to use at any time during their program run, the choice of modes is the student's. A student may choose to use each of the modes simply by following the numerical order of the modes, that is 1,2,3,4. Each mode may be investigated a number of times using different values for the parameters of the simulation model. Other students may use the modes in what may seem to an observer as a random and illogical manner. When this happens an observer might construe the student to be wandering through the program hoping to pick up as much information as possible but having no real strategy for doing so. Alternatively, this "wandering" might be construed as purposeful. It might represent the student's desire to observe particular behaviours of the simulation
model, as a means of fully using the capabilities of the program. It might, for example, represent the student's desire to test hypotheses. I believe that the most effective way of using the various modes of the POND programs is to use modes 1, 2, 3 and 4 in that order. By "effective" I mean way which will improve the chances of a student understanding all that is displayed by the computer during a program run. In this way, each mode builds on the information obtained during previous modes, in other words, I am suggesting that there can be a hierarchical acquisition of concepts. If a student uses the modes in any other order then they might encounter difficulties in efficiently (that is in the shortest time) acquiring concepts which the program is encourage the construction of by the student.

The student who remains on the recommended (at least implicitly) modal path, that is who uses the modes in the order presented by the program (1,2,3 and 4), might be feeling inhibited or restricted by the structure of the program. In Kemmis' terms (1977b), for this type of student the program would have a "strong pedagogical functional structure". It might thus be predicted that such a student might show fewer "experimental" activities than a student for whom the program has a weak pedagogical functional structure.

From the program developer's point of view, I believe that it is necessary to look at the reason why students can demonstrate different choices of modal order. If the program developer strongly believes that the the most "efficient" use of a program is by using the various modes in a particular order, then it might be common sense to impose that order of modal use on the student. However, the program developer should be aware of the possibility that by restricting a student's choice of movement through a program, the learning potential of that program might be reduced. Alternatively, a student might find
that a program is more stimulating if no restrictions in modal order are imposed. The student might find it beneficial to be able to flip from one mode to another, and even back again, to test hypotheses for example, checking their findings as they do so. By allowing this kind of freedom for the student the program developer may be encouraging, or at least not inhibiting, some of the higher cognitive activities such as experimentation in the form of hypothesis testing and problem solving.

It would be advantageous to be able to describe, in some general way, the type of pathway a student has taken through the various modes of a program. If expressed in a mathematical form, it should be possible to correlate this factor to various cognitive activities demonstrated by a student. It is possible to show the pathway graphically if the mode selected by a student at every change of mode is plotted. If a student uses a program as implicitly recommended by the program structure, that is modes 1,2,3,4 a perfectly straight line having a regression coefficient of +1.0 would be obtained as in figure 8.2. If the modes were used in the reverse order, that is 4,3,2,1, the regression coefficient would be -1.0, as in figure 8.3. If the modes were used in an apparently random order, for example 1,4,2,3,2,4,2,1 and then 3, the regression coefficient would be 0.0 as in figure 8.4.

I have called the regression coefficient value the "invariability factor" since if it has a value of +1.0, its highest value, the student would not have varied from the implicitly recommended modal order during their program run.
Figure 8.2  Example of a modal order having a regression coefficient of +1.0

Figure 8.3  Example of a modal order having a regression coefficient of -1.0

Figure 8.4  Example of a modal order having a regression coefficient of 0.0
For each student's profile of their use of a POND program I have been able to produce an indication of the frequency at which they had demonstrated certain cognitive and other activities. The full list of fourteen factors considered in these studies is given below:

i. Invariability factor,

ii. Number of preconceptions demonstrated before the student's program run,

iii. Number of sets of data INPUT during the student's program run,

iv. Number of actions demonstrated - for example, such as to "compare sets of data", that is strategic actions,

v. Number of actions demonstrated plus activities associated with the selection of appropriate enquiry skills,

vi. Number of observations made explicit during the program run,

vii. Number of concepts made explicit,

viii. Number of valid concepts made explicit,

ix. Number of invalid concepts made explicit,

x. Number of predictions made,

xi. Number of obvious theory-laden observations made.

xii. Number of hypothesis testing activities,

xiii. Number of experimental activities (that is, predictions plus activities which show the selection of the appropriate enquiry skills plus hypothesis testing activities),

xiv. Number of dialectical statements made during the program run.

The data (appendix 18) for all students using a particular POND program were compared with the data for students using each of the other POND programs using a correlation coefficient analysis. The most significant correlations (that is greater than 90% significance) are
shown diagrammatically in figures 8.6, 8.7, 8.8 and 8.9 and in full in appendix 19.
Figure 8.6  Correlations Between Cognitive Activities of Students using POND-2

Lines indicate a correlation between factors. + or - indicate a positive or negative correlation. Numbers refer to the level of significance of the correlation values (see appendix 19 for the correlation values).
Figure 8.7 Correlations Between Cognitive Activities of Students using PONDQU

Lines indicate a correlation between factors
+ or - indicate a positive or negative correlation
Numbers refer to the level of significance of the correlation values
(see appendix 19 for the correlation values)
Figure 8.8  Correlations Between Cognitive Activities of Students using PONDGAME

Lines indicate a correlation between factors
+ or - indicate a positive or negative correlation
Numbers refer to the level of significance of the correlation values
(see appendix 19 for the correlation values)
Figure 8.9  
Correlations Between Cognitive Activities of Students using POND2HELP 

Lines indicate a correlation between factors  
+ or - indicate a positive or negative correlation  
Numbers refer to the level of significance of the correlation values  
(see appendix 19 for the correlation values)
8.3.4 Evidence for the relationship between parts of the Interaction Model

The results obtained from the analysis of student program runs in terms of the various cognitive activities demonstrated, have certain implications for the Interaction Model. In this section I want to examine the nature of these implications and show how the effect of program structure can influence the cognitive activities demonstrated by students. Figure 8.1 shows how I believe the various parts of the Interaction Model influence each other. I will examine a number of these interrelationships with reference to the correlations that might exist between parts of the Interaction Model of Learning shown below:
Preconceptions can either be regarded as consisting (a) of the body of knowledge related to those contained within the simulation model that the student brings to the learning experience, that is, pre-existing conceptual beliefs; or (b) of concepts that have been formed during previous learning episodes in the student's current program run.

This body of knowledge could affect a number of the stages in the interaction process. (i) It could affect the student's strategic style in that it could encourage, for example, various experimental activities to see whether the simulation model behaved according to the student's preconceptions. (ii) Preconceptions, or a lack of related concepts, should influence the type of data that the program user inputs. It may be that values similar to those the student believes to represent the real world values are input; it may be that a lack of related knowledge causes the student to guess the values that they input, that is to "button-push". (iii) Prior knowledge and previous experiences will influence what the program user perceives in the output data. In other words, it will determine whether s/he interprets it correctly, whether s/he perceives all of the relevant points or merely concentrates on parts of the data with which they are familiar. (iv) Prior knowledge could influence the formation of concepts in that it could limit the nature of concepts unless a marked change in the student's conceptual structure takes place.
(i) The effect of preconceptions on the strategic style
   exhibited by the program user

The term "strategic style" implies purposefulness on the part of the student, and includes a number of different activities. Perhaps this is best described as being a hierarchy of activities. This hierarchy being a number of activities of which a statement of intent, for example to compare data, is relatively simple, whereas hypothesis testing and experimentation are higher and more complex cognitive activities which are included under this heading.

In addition, a rather obvious strategic action of relevance to these studies is the "invariability factor". This invariability factor could be an expression of whether the student, that is the program user, has a strategic style strong enough to overcome the "pedagogical functional structure" of the CAL program. If s/he has this strength then an invariability factor of less than +1.0 could represent the student's will or drive to experiment for example. On the other hand, if the program's pedagogical functional structure is stronger than the student's "strategic drive" then the student is likely to follow whatever the program directs, that is could follow the implicitly recommended modal order and have an invariability factor of +1.0. However, a positive correlation between the number of relevant concepts a student begins this type of learning experience with and the invariability factor is only found for those who used POND-2 and POND2HELP (99 and 95% significance levels respectively). In other words, the less the student knows about the food pyramid concept, the more likely s/he is to vary the order of using the modes of these two programs.
I have previously indicated that this could be viewed as (a) an aimless wandering through the program to pick up whatever information they can glean by so doing, or (b) a flexible use of the program because of the desire to use the program in an experimental and guided way, and not to be confined to a sequential use of the modes with the obvious limitations this would bring to bear on the knowledge that is obtained from studying the OUTPUT data.

It is the second of these explanations which appears to have the most credance. For both POND-2 and POND2HELP there are strong negative correlations (95% levels of significance) between the invariability factor and hypothesis testing activities. For POND-2 there is also a similar negative correlation between the invariability factor and all forms of experimentation. It would thus seem that the functional structure of POND-2 and POND2HELP has not overcome the experimental drive of the students participating in these studies, whereas PONDQU, the only other POND program to have a modal structure, the structure has destroyed the relationship between the order of the use of modes and experimentation. Indeed, in these studies PONDQU has encouraged significantly less experimental activities than POND-2 (the mean number for POND-2 and PONDQU being 4.0 and 1.4 respectively, representing a difference between the means significant at the 99% level). POND2HELP also encouraged less experimental-type activities than POND-2 (POND2HELP mean value for experimental activities being 2.0, representing a difference between the means significant at the 98% level).
Why should having a relatively good knowledge of the concepts contained within a simulation model reduce the number of experimental-type activities demonstrated by students using certain types of CAL program? It could be that this non-experimental use of a CAL program takes place because the student feels that they already know "all about" the behaviour of that model or system. Thus, in using the program the student might merely wish to follow through the various modes (a) to see that it is providing the kind of data that they would expect of such a simulation and (b) perhaps to "fill in" deficiencies in their conceptual structure, or to increase the number and range of exemplars they have of such concepts.

It is interesting to look at the order in which the students used the various modes of the programs and the reasons they provide for so doing. Similarly, the mode with which they commenced their program run and again their reasons. These are summarised in the following tables (figures 8.11 a and b)
Figure 8.11a  Frequency by which modes used to commence program

<table>
<thead>
<tr>
<th>Mode commenced Program with</th>
<th>Number of students</th>
<th>Percentage of students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4</td>
<td>82  7  7  4</td>
</tr>
</tbody>
</table>

Figure 8.11b  Reasons for starting program with a particular mode

<table>
<thead>
<tr>
<th>Mode started program with</th>
<th>Reason</th>
<th>No. Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Best to observe pond first</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>Because is first mode</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>See numbers in pond</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Most interesting mode</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Thought first would be only mode could use</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>To see how populations are related</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>First mode to come to mind</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Because likes fishing</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Wanted to see what pollution would do</td>
<td>1</td>
</tr>
</tbody>
</table>
Most of the students (82%) who used POND-2, PONDQU and POND2HELP started their use of the program with mode 1 (observing the pond using data provided by the program). It is a means of observing the behaviour of the ecosystem when it is at equilibrium and without any external factors causing disturbances in its equilibrium. 65% (15) of the students who commenced with mode 1 gave this as the reason for so doing. A further 13% (3) of the students wanted, more specifically, to see the "numbers" in the pond. There was, however, a proportion of the students (30%) who used mode 1 because it was the first of the modes indicated in the program. For these students there was no reason other than "it was number one". In other words, for these students it was a case of "push a button and see what happens".

This lack of real reason for choosing various modes of the program is also often found when students "choose" not only the first mode but also when they choose the remaining modes during their program run. Of the students who used these three POND programs, and for whom reasons of any sort were given in the interview, 45% (5) only wanted to see what would happen, 54% (6) had an interest or liking of a mode (for example, one student (MB) had done a project on pollution at school), for 45% it was the logical or sensible thing to do, for 1 student it was because he didn't like the alternatives. For 1 student the various modes were used in a particular order because of his wish to experiment!

Thus, the majority of the students using POND-2, PONDQU, and POND2HELP began with mode 1. This is where the program designers wanted students to begin, although the students can, with a little thought, begin by using mode 2 equally as successfully. To begin with mode 3
or 4 would, in all probability, mean that the program user would be
lacking some of the fundamental concepts necessary for a full
understanding of the data being presented by these two modes.

(ii) The effect of preconceptions on the nature of INPUT data

There appears to be no evidence of a correlation between the number of
concepts relevant to the food pyramid concept which are demonstrated
before the use of a POND program, that is the relevant pre-existing
conceptual beliefs, and the number of sets of INPUT data. However,
there is some evidence that the student's pre-existing conceptual
beliefs influence, at least to some extent, the values which they
INPUT. Such influencing factors can come from knowledge gained in
real-world experiences as the following quotations will show:

"I chose June to pollute the pond because people go on picnics
at that time of the year and throw litter away. In winter
there might be fumes from chimneys."
(ST: POND-2 program run)

"Middle of the year and all herbivores - nice sunny weather -
good conditions - more likely to be polluted by people
dropping things into the pond."
(JB: PONDQU program run)

"I wouldn't fish in the winter."
(CH: PONDGAME program run)

"With the pollution one...I was pressing...the different
levels, because I was imagining what it would be..."
(FQ: POND2HELP interview)

In contrast to these "informed" INPUTs, it seems from what many of the
students said during their post-run interviews that values were chosen
either by guesswork or by choosing median values. This was especially
so when these values were INPUT as the student's first attempt of that
part of the program. Experience in using the program would usually
dictate the value to be INPUT in the following, related episodes.

(iii) The effect of preconceptions on the nature of observation statements

Previous learning experiences should have taught the student what is fruitful to observe. They should, at the age of 16 years or older, be able to interpret graphical and tabular forms of data. However, complex graphical and tabular presentations can sometimes lead to mistakes in interpretation. More seriously, it appears that certain preconceived ideas and concepts held by a student can lead to incorrect observation statements being made. The formation of such invalid observation statements might lead to the formation of incorrect concepts. To some extent the formation of invalid observations (or perceptions) can be overcome by the careful presentation of the OUTPUT data by the program developer and writer.

Student's imaginations can become active. The activity of student's imaginations is often high when they are using CAL programs. For example, the "pond" in these programs was imagined by some students as being a fish farm (even if the program was not PONDGAME!), as being large, as being small, that the fishermen weren't fishing because it was cold! Such imaginations were usually not based on any evidence being presented by the program. Such imaginations were therefore products of processes taking place within the student's mind evolving from their understanding of similar experiences.
The following is an example where imagination came into play and invalid observation statements were made. DW (POND-2) polluted the pond using the highest level of pollution available in the simulation. This action will result in the death of all of the pond organisms. This extinction of the pond organisms is perceived by DW, but, in addition, he makes statements that are invalid in terms of the data presented by the program, an extract of which is given below:

<table>
<thead>
<tr>
<th>PHYTOPLANKTON</th>
<th>HERBIVORES</th>
<th>FISH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x 10^9)</td>
<td>(x 10^6)</td>
<td>(ACTUAL NO.)</td>
</tr>
<tr>
<td>SEPT.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>OCT.</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

On seeing this data, the student made the following comments:

"...it probably kills the phytoplankton first of all, cutting out the light or changing the chemical balance in the water, and thus affecting the herbivore and fish numbers. Once the phytoplankton are dead, the others will die."

Somehow the data has given the student the impression that the phytoplankton died before the other organisms (1). One obvious reason why this should be so is that he had not realised that the "1" for the phytoplankton in September really represented 1 x 10^9 plankton. If the student had not realised this, then it would have been a simple matter of extrapolation of the data to see it would have been the most likely population to have died before the other two populations. The plankton were, apparently, the nearest population to zero and therefore extinction. During an interview I asked DW why he had said the plankton had died first:
"I really had that theory in my mind....I think the way I looked at the data was probably biased because in my mind I was very lazy...I find it much easier if I had the graph to compare the data...I probably saw it happen, but it probably didn't because I was only looking at individual pairs of data, comparing the data, comparing them only, without realising. Subconsciously putting a bias on what I saw ."

By possessing the concept that the plankton are directly or indirectly required by both of the other pond organisms for the maintenance of life ( 2 ) influenced what he saw ( 3 ).

This is not a unique example. The same kind of imaginative response was, for example, produced by another student (ST: POND-2) in almost the same context as this example. A recent scientific paper (Hetherington [1983]) has revealed similar cases where scientific observations have reflected "personal biases" of the research worker. Hetherington cited famous scientific personages such as Galileo and Newton.

It thus seems as if students do not always look at information in the same way as a subject-matter expert, or even as a subject-matter expert would wish a student to look at the information that is presented by the simulation program. A program developer, in all probability, believes that he is presenting students with a simulation with which they can experience for themselves the behaviour of the system and acquire concepts which will explain this model's behaviour. The program developer might believe that the knowledge that the student acquires by using the simulation will be the "knowledge-as-presented" by the CAL program.
We must not necessarily assume that the "knowledge-as-conceived" by a program user will be the same as the "knowledge-as-presented" by the CAL simulation. Preconceptions, a lack of experimental and problem-solving skills, poor observation techniques can all affect the final result of a student's learning experience. Program developers should be concerned to present information to the users of a program in a way that will facilitate the formation of valid perceptions and conceptions.

(iv) The effect of preconceptions on concept formation

There appears to be no direct correlation between the number of concepts related to the food pyramid concept and the number of concepts that the student acquires during their use of a POND program (except for PONDGAME where there is a negative correlation between the number of preconceptions and the number of invalid concepts formed). I will look at concept formation in greater detail in chapter 9, and thus I do not intend to pursue this matter any further here.

(v) The effect of strategic style on INPUT data

The term "strategic style" is not being used at this time to describe the program users cognitive, learning strategies, or "executive style" (Laurillard, 1978b). Instead, I am restricting myself to examining the way in which program users approach the INPUT of the various parameter values to obtain OUTPUT data. From the OUTPUT data, or "subject matter", the person can then employ their "executive style" to discover the various relationships between parts of the simulation model.
Strategic style is being taken to mean, therefore, the strategy a program user employs to provide information to the computer. This may include "button-pushing", various levels of experimentation, or providing a median value when the effect cannot be predicted and the person wants to play safe. The nature of the strategic style will depend on the person using a program, their previous experiences, motivation to learn from the program etc. However, I do not wish to pursue the matter any further here since I will examine whether or not students use CAL simulations in a "scientific" way in chapter 10.

(vi) The effect of having a large number of sets of INPUT data

A person who makes a relatively large number of INPUT actions will probably look at a wide range of behaviour patterns of the simulation model. A person provides a large number of sets of INPUT data would, therefore, be expected to have the opportunity to make more observational statements than a person who provides relatively few. On the other hand, there will also be a personal effect in that some people will be able to obtain more information from a particular set of data (or subject matter) than another.

A correlation appears to exist between the number of sets of data INPUT and the number of observation statements that are made by the students in these studies who used POND-2 and POND2HELP (both correlations being at the 95% level of significance). A person who provides a large number of sets of INPUT data is likely to make a relatively large number of observations about the simulation model and will, as will be shown later, make a relatively large number of valid conclusions about
the behaviour of the model. However, a direct correlation between the number of sets of data INPUT and the number of valid concepts demonstrated only exists for students using POND2HELP (95% level of significance).

(vi) The effect of making a large number of observation statements

For all four POND programs there is a correlation between the number of observation statements made by a student and the number of valid concepts demonstrated. It could be argued that this correlation merely represents the capability of certain students to provide observation statements and statements representing their understanding of relationships existing within the simulation model. However, I believe that, although this may be true, it is also true that if a student is encouraged to make observations then s/he is more likely to form these conceptual relationships. This correlation that appears to exist for students using all of the POND programs tends to support this. Students who are capable of making explicit statements could be demonstrating invalid as well as valid relationships. A correlation between the number of observation statements and the number of invalid concepts demonstrated does not exist except for students using POND-2. It seems therefore a useful activity to encourage students to see as much as possible in the OUTPUT data since it is probable that by so doing the formation of valid concepts will be encouraged.
8.4 The Effect of Program Structure on Learning Behaviour

In the previous section (8.3) of this chapter I indicated that the different POND programs appear to encourage a different range of cognitive activities. I now want to look at how various intrinsic and extrinsic factors affect the learning behaviour of students who use the POND programs.

To achieve this aim I have adopted the procedure of "if...then..." I will choose a suitable starting point for a student who has demonstrated a particular characteristic and see what happens if... (using the correlations shown in appendix 19 and figures 8.6 to 8.9 inclusive). From the "then" I once again see what happens "if...", and so on until the process cannot be taken any further. Because the structure of the POND programs is somewhat different and thus because different correlations appear to exist, it will be necessary to choose different starting points for each of the POND programs. The end result of this study are a number of scenarios which I believe show the effect that program structure can have on learning behaviour.
8.4.1 The effect of different levels of understanding of the concept "food pyramid" on the cognitive behaviour of students using POND-2 and POND2HELP

Students have somewhat different pre-existing conceptual structures and thus exhibit a different understanding of the various concepts subordinate to the concept "food pyramid" (as demonstrated in the pre-program run interview). It is to be expected, therefore, that they will exhibit different approaches to using these programs.

For the first scenario I want to look at the probable behaviour of someone who comes to use POND-2 with an apparently has a good understanding of the concept "food pyramid".

By possessing some considerable knowledge of the food pyramid concept, the student's strategic style for using the program is one which involves little experimentation. The student, in all probability, will use POND-2 following the recommended modal order (that is, modes 1, 2, 3 and 4). In other words, he will not want to wander from the path which the program implicitly indicates that he should take. He will not "see what happens if...". This is substantiated by the high negative correlation that exists between the number of preconceptions and the number of hypothesis testing activities that students using POND-2 demonstrate.

Alternatively, if the student has a good understanding of the model's behaviour, there is a low probability, or perhaps desire, to test their understanding of the model or system. Perhaps this is because the system seems familiar? Since there is a correlation between the number of experimental types of cognitive activity and the number of sets of INPUT data, it follows that students in this scenario are
unlikely to INPUT a large number of sets of data. This may be because this type of student does not need to achieve so much when working with a simulation which appears to be a familiar one. It also follows that since this type of student does not INPUT many sets of data, neither does he make many observation statements nor demonstrate the formation of many valid concepts.

On the other hand, users of POND-2 who have little or no understanding of the concept "food pyramid" and its subordinate concepts, will probably exhibit a pattern of behaviour opposite to that I have just described. These students tend to use POND-2 using experimental-type cognitive activities. Because they have very little knowledge about the system they are unable to INPUT data which will cause the simulation model to respond in a known, or predicted, way. The student will want to "see what happens if...". As s/he formulates ideas as to how the model behaves s/he tests these ideas, and perhaps modifies them according to the observations that s/he makes. These experimental types of cognitive activity are demonstrated by the student in a number of ways. This type of student tends not follow the recommended modal order. Secondly, the students will tend to produce and test hypotheses about the relationships of the organisms in the pond and how these organisms behave under different situations. These students tend, therefore, to INPUT a relatively large number of sets of data, probably because they need to find more about the model than do students who already possess many of the concepts forming the superordinate concept. By inputting a large number of sets of data, the student is likely to make a large number of observations and thus demonstrate a large number of concepts related to the food pyramid concept.
It thus seems that it is the student who comes to use POND-2 knowing little about it beforehand, is capable of making the best use of the program. They will use it in a flexible way to find out as much as they can about the model. They will demonstrate more concepts during their program run than the student who comes to the program with a considerable number of related preconceptions. Previous, related knowledge, appears, therefore, to interfere with the learning activities demonstrated by users of this program.

In many ways the structure of POND2HELP promotes a similar behaviour of students who use it as does POND-2. Students who start using the POND2HELP with a good understanding of the food pyramid concept (in terms of the number of relevant concepts demonstrated in the pre-program run interview) tend not to experiment, tend to INPUT few sets of data, make few observation statements and demonstrate few concepts. As with POND-2, therefore, the best use of the program is made by those with little prior knowledge.

A similar criterion to the number of concepts demonstrated during the pre-run interview is the "level-of-understanding" (L.O.U) which is calculated according to the answers provided by the students using POND2HELP to questions posed at the beginning of, and throughout their program run. Those students who have a high mean L.O.U. (either through having a good prior knowledge, or becoming knowledgeable through using the program) tend to question what they see. This dialectic response may be encouraged by the questions through which the L.O.U. is calculated. These questions could stimulate students to question concepts they hold. The questions might, for example,
provide an alternative concept which the student is more willing to believe, and thus the process of conceptual exchange takes place. Dialectism, for students using POND2HELP, appears to encourage experimentation (rather than just hypothesis-testing) and the formation of predictions. Dialectism also appears to encourage the formation of invalid concepts (less likely to develop valid concepts?). It is here that the two scenarios for those students using POND2HELP may be similar, although they had somewhat different starting points.

The questions and the advice provided in POND2HELP doesn't, therefore, seem to have changed the program's functional structure when the cognitive behaviour of the students using POND2HELP and POND-2 are compared.

8.4.2 The effect of following the implicitly recommended modal order on the cognitive behaviour of students using PONDQU

Unlike the students using POND-2 and POND2HELP, students using PONDQU who have a good prior knowledge and a poor prior knowledge appear to show no difference in their activities. The answer for this marked difference must lie somehow with the questions that are included in PONDQU since this is the only difference existing between the programs. The questions included in PONDQU are intended to provide students with a good basic understanding of the simulation model and the food pyramid concept. They provide an understanding of food chains, the place of each organism in the food chain, and an idea of the relative size of each of the populations. Consequently, even if a student does not commence the program run with a good understanding of the food pyramid
concept, s/he will be provided with much of the prerequisite information for using the simulation.

Since I cannot use the same starting point as previously, I will commence this scenario by selecting students for whom PONDQU has a strong f-structure with respect to following the implicitly recommended modal order. Students using PONDQU following the implicitly recommended modal order, have an invariability factor of +1.0. They appear to demonstrate more concepts than those students who have a lower invariability factor. It is, however, difficult to see from the correlation factors between the student's various cognitive activities why this should be so. The cause seems to arise from the student's capability to produce learning situations, that is have strategic actions which enable him to make observations. Unlike POND-2 and POND2HELP, it does not seem to make any difference as to the number of sets of INPUT data a student uses to obtain information about the model's behaviour. All students appear to be provided with enough information. There are, however, positive correlations between the number of strategic actions (including enquiry skills) that a student demonstrates and (a) the number of observation statements that are made, (b) the number of valid concepts that are demonstrated, and (c) the number of hypothesis-testing activities demonstrated. There is also a positive correlation between the number of observation statements made and the number of valid concepts demonstrated. The scenario might thus be: by making a number of strategic actions and by various hypothesis-testing activities the program-user is able to make observations and thus demonstrate a relatively large number of valid concepts. Users of PONDQU who do not demonstrate many strategic actions or do not test hypotheses are unlikely to gain much from this
program in terms of valid concepts that they are able to demonstrate (or acquire).

8.4.3 The effect of making a large number of strategic decisions on the cognitive behaviour of students using PONDGAME

PONDGAME, as might be predicted, encourages students to make strategic decisions, to experiment, and to make and test hypotheses. It does not seem to matter what the student's theoretical background is, that is whether they demonstrate a good or a poor understanding of the food pyramid concept in the pre-run interview, the program's structure allows all to succeed equally well. There is no correlation between a person's prior knowledge and the formation of valid concepts. PONDGAME appears to encourage the demonstration of more valid concepts than either of the other three POND programs. However, the valid concepts demonstrated by those using this program are often not directly related to the food pyramid concept (e.g. "fish eat herbivores"), but are statements more in the nature of causality (e.g. "too many fish caught in the beginning of the year"). This latter type of concept however does show the student's appreciation of factors affecting the ecosystem, and thus indirectly show an understanding of the simulation model.
8.5 Reflections on the Use of the Interaction Model in the Study of Learning

8.5.1 The Validity of the Model

By using the Interaction Model to describe the events which take place when a person uses a CAL program, it was my intention to describe the detail of the student-CAL interactions promoted by these programs. In describing this detail I hoped to see how students used the programs and thus, the factors that influence their cognitive activities. This, as I have previously indicated, requires detailed protocol analysis. The detailed analysis of students' protocols enables a quantitative comparison of learning behaviour to be made. Such a quantitative comparison must not be taken as being intrinsically true. Students do not always make overt statements of what they are seeing nor of the rules/laws/axioms etc. they have learnt by using the simulation model. Consequently, some inaccuracy is inherent in the data obtained in this fashion.

By using the correlation data, however, merely to guide thinking, to make generalisations, rather than to rigidly compare program with program, they can be a useful aid to understanding how the programs work. I believe that I have done this when producing the scenarios. These scenarios are of use in that, I believe, they indicate or predict how students might behave cognitively under various circumstances. They are, in many ways, those one would have expected. PONDGAME, for example, appears to encourage various experimental types of cognitive activity which are predictable activities for anyone playing a game.
The Interaction Model would seem to be a valid method for the analysis of student learning behaviour in that it has shown that POND-2 and POND2HELP encourage a similar pattern of behaviour. POND2HELP differs from POND-2 in that it asks questions of the students understanding at times during their program run and it provides help when this is requested. Both the questions and the help provided were designed so as not to be too intrusive. They do not try to dictate what the student should believe, nor dictate what the student should do. Thus, I would not have expected a marked difference in learning behaviour of students using POND-2 and POND2HELP. In addition, the method of analysis does appear to be sensitive. It detected, for example, a larger number of dialectic statements encouraged by the structure (questions) of POND2HELP.

The purpose, that of presenting a "true" picture of events and explaining them, of this form of research must always be borne in mind. As Parlett (1977) says:

"Presenting a recognisable reality is the major means of validity testing..."

In presenting case-studies, where one is attempting to explain behaviour of individuals in a learning situation, one method for determining the validity of that work is to refer back to the participants for their opinion of the analysis. The participants are asked whether they believe the researcher has produced a true representation of how they performed in the learning situation under study (for example see Parlett, 1977; Simons, 1977; Smith, 1977; Kushner and Norris, 1981; Terhardt, 1981). I adopted this procedure as a means for testing the validity of the approach I adopted to produce these scenarios. However, as the completed scenarios were
only available at a late stage in these studies, I have only been able to interview five students, all of whom used POND2HELP. These students included those who had a "good" initial understanding and those who had a "poor" initial understanding of the food pyramid concept. These represented both extremes and the median position of the starting point for the scenario. Figure 8.12 shows the various details of how these five students used the program and also how I would predict they would behave (based on the number of concepts with which they began their program run and the correlations indicated in the scenario).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Invariability factor</td>
<td>.85</td>
<td>-.62</td>
<td>-.02</td>
<td>-.21</td>
<td>.31</td>
</tr>
<tr>
<td>No. Hypothesis testing activities</td>
<td>0</td>
<td>-.24</td>
<td>1 ,02</td>
<td>0</td>
<td>.35</td>
</tr>
<tr>
<td>No. Inputs</td>
<td>12</td>
<td>9.3</td>
<td>21</td>
<td>15.4</td>
<td>7</td>
</tr>
<tr>
<td>No. Observations</td>
<td>52</td>
<td>45</td>
<td>101</td>
<td>57.4</td>
<td>36</td>
</tr>
<tr>
<td>No. Valid Concepts</td>
<td>5</td>
<td>4.1</td>
<td>19</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 8.12: Observed and predicted values for activities seen as significant in the POND2HELP scenario.
During the interview with each of the students (which was tape-recorded and transcribed verbatim) I predicted how each of the students would behave during their program run. My predictions were based on the number of concepts they had demonstrated during the pre-run interview.

DG was the only student to have a reasonably good knowledge of the food pyramid concept before the program run, and thus the only student who I would predict not to experiment very much whilst using the simulation. MB and RC2 were at the opposite end of the "spectrum", and thus I predicted that they would experiment. FQ and SB showed an "average" understanding (being at the median value for students who used this program), and thus I predicted that they would experiment, but expected some doubt to be expressed by these students as to whether they had used the program very experimentally.

Each student agreed with my predictions except FQ who had some reservations that she had been experimenting all the time saying:

"I think that's fairly reasonable!" (my emphasis)

The data shows that my predictions were only wrong, in terms of the data presented in Figure 8.12, in the case of RC2 who, though saying he had experimented, showed no hypothesis testing activities at all; who said he had learnt a considerable amount about how the pond worked, but who demonstrated the formation of no valid concepts at all.
The students participating in these studies thus showed indirectly their belief in the validity of the Interaction Model and the way I had used it to produce a scenario. However, the data shows that for individuals, rather than the group as a whole, the model, basing the predictions on one factor, can fail to predict how that person will behave.

8.5.2 The Description of the Learning Process

The Interaction Model can thus be used to describe the overall process of the student-CAL interaction, it can be used to determine the effect that various factors can have on the learning process. In addition, unlike other methods of protocol analysis (for example, Laurillard 1978a) these diagrammatic representations of learning show the episodic, or non-continuous, nature of the learning process. It has been suggested that the learning process is a continuous process; one event leading to the next as shown in step A of the following diagram:
Instead, the students often seem to use a program in discrete stages, the findings of each stage possibly being related to another at a later stage in the program run, for example, by comparing data obtained at different times during their program run, by remembering what they had seen, what they thought had happened etc.

Overall, the Interaction Model has enabled me to represent the student-CAL interaction in a clear and detailed manner. It is a method which I have found to encourage a deeper analysis of the students' cognitive processes than I might otherwise have been capable of performing. The Interaction Model is not only an analytical tool, but a representation of my understanding of the student-CAL interaction.
Chapter 9
The Promotion of Concept Formation by the POND Programs

9.1 Introduction

The use of the POND programs is intended to be a meaningful experience either in promoting the acquisition of the various concepts concerned with food pyramids and the dynamic nature of ecosystems, or in providing further exemplars of these concepts for those who already possess these concepts.

I have already described in chapter 7 how I attempted to use concept maps to follow and describe concept formation as individual students use the POND programs. In chapter 8 I have described the Interaction Model representing the student-CAL interaction which can lead to concept formation and various other cognitive activities. Using the Interaction Model to analyse student protocols allows some of the different cognitive behaviours and factors affecting behaviour to be described. In this chapter I will look in greater depth at concept learning activities and the nature of the concepts so formed.
9.2 The POND Programs and Forms of Concept Learning

9.2.1 Causal Explanations

In CAL simulation programs, the behaviour of the model is being observed by the student. For concept formation to take place, it is necessary for the program user to be able to determine the cause of certain events.

"It is important to learn that an event A is regularly accompanied by another event B."

(Hanson, 1969; page 271)

But, as Hanson (ibid) also states, it may be more important to know what causes event B to follow event A. To know a cause enables one to either prevent event B from taking place, or how we can encourage the occurrence of event B. If we remove, or prevent event A from taking place, and if event B does not take place, we can say that A causes B. If we provide the necessary conditions for event A to occur, and event B takes place, then we can also say that A causes B.

It is necessary, of course, to ask why should two events be related by a person who hypothesises that one event (A) is the cause of the other event (B). One obvious explanation is that event B (the effect) is close, either in space or time, to event A (the cause). There is also the possibility that the repeated perception of event pairs, event B following event A, will be construed as cause and effect. To construe such an event-pair as cause and effect might result in a misconception. It may be that event B following event A is merely a coincidence. To prevent the retention of such a misconception it is necessary to establish the causal law. Hanson (1969) comments that:
"Events which we customarily refer to as causes are rarely thought of in neutral terms. Theory-loaded nouns and verbs are used rather than phenomenal nouns and verbs... The difference is that between seeing how and seeing that... Effect-words are laboratory assistants' words... Cause-words are research scientists' words."

Effect-words and cause-words show a difference in the level of understanding, the extremes of which may be seen in "lay science" and "scientist's science".

During their use of a CAL simulation students might see two types of causal agent:

i) This type of causal agent is represented by figure 9.1.b. Here the causal agent is perceived as an action, or event, that the student is responsible for initiating, by providing a particular set of INPUT parameter values.

ii) Here the causal agent is a perceived event that occurs during the simulation, and is seen as the cause of a following perceived event. Two such events would be seen as cause and effect either because the student has a repeated perception of this event-pair, or because the second event is seen to occur very soon after the first.

During their use of a simulation program, individuals may:

i) have preconceived ideas as to what should happen when certain action events occur, and that these concepts are tested against the subsequently perceived events; such a method of concept learning may be regarded as a hypothetico-deductive form.

ii) not be able to explain certain perceived events using their present conceptual structure. Consequently, an explanation must be sought for these events which are regarded by that individual as surprising. Only surprising events or data will lead to concept
formation. If an event is not regarded as being surprising, then it must be regarded by that individual as capable of being explained by their present conceptual structure.

If an individual sees a "surprising" event, s/he will believe that they do not possess a concept to explain that event. Consequently they will try to create one by intuition. If an event is not seen as surprising there are two options: they possess the concept; or they believe they possess a suitable concept which is capable of explaining that event.

According to Peirce's Abduction Theory, the perception by an individual of a surprising event would stimulate that person to provide what seems to them as a reasonable hypothesis, a cause, to account for that event. This hypothesis might normally be expected to be tested if the exercise were a scientific one. According to Peirce, such a scientific testing of a hypothesis consists, in the first part, of the process of deduction (to decide on a suitable experiment by which it could be tested and the results which should be obtained by that experiment), and in the second part, of the process of induction (to perform the experiment and compare the predicted results with the results obtained by the experiment).

Not all individuals behave in such a rigorous scientific manner! Hypotheses may be put forward as an explanation for a particular event, but left for later confirmation or rejection. In the meantime that concept is retained as an acceptable concept. However, I do not wish to pursue Peirce's philosophy any further at this point. I will examine Peirce's theory in greater depth in chapter 10.
9.2.2 Forms of Concept Learning

In these studies I have been able to detect four forms or strategies of concept learning, the principles of which are shown diagrammatically in figures 9.1 (a-d).

In the narrowest sense, concept learning is merely the creation of a hypothesis to explain an event or series of events. This concept can later be shown to be correct or it can be rejected as an unsatisfactory explanation. In learning situations involving the use of unfamiliar CAL simulations, it might be expected that concepts are developed intuitively by an individual to account for the behaviour of the model.

On the other hand, if the simulation model appears to be a familiar one, concepts within the individual's existing cognitive structure might be used to explain the perceived behaviour. These concepts may be tested. Such testing would be carried out by a hypothetico-deductive method.

Of the four types of concept learning that I have been able to distinguish, three (types A, B and C) involve the intuitive adoption of a reasonable concept to explain the behaviour of the simulation model. The fourth form of concept learning (type D), the hypothetico-deductive method, represents the testing of a hypothesis to determine whether it is a suitable concept for that simulation model.
(a) **Type A Concept formation**

(b) **Type B Concept formation**

(c) **Type C Concept formation**

(d) **Type D Concept formation**

**Figure 9.1** **Forms of Concept Formation**
Type A Concept learning (Figure 9.1.a)
This involves the intuitive creation and adoption of a hypothesis to explain a perceived event for which the cause is not obvious. The created concept must be reasonable, it must make sense (to the individual) within the context in which the event occurred. The following extracts are from observation protocols, and illustrate this form of concept learning:

Example 1: (DG: POND2HELP)

<table>
<thead>
<tr>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chose a high level of pollution in February.</td>
<td>The numbers decrease drastically. The populations killed off in March completely. The plankton recover their numbers in April. Probably spores.</td>
</tr>
</tbody>
</table>

This can be shown diagrammatically:
subsequently surprised to see the plankton reappear (recover) in April. Why should the plankton recover? He puts forward the concept of plankton surviving as spores (comment 4). This is a feasible concept since he appeared to know what plankton were, and that they can exist as spores or spore-like structures.

Example 2: (M& POND-2)

What shall we do first?
Sudden dramatic increase in fish in May. It seems that there are most herbivores and phytoplankton around. Why do fish decrease in March?
The decrease may be due to light decreasing during the year (therefore, they are all related).

Student Action
Choose mode 1.
Continued to Year 2.

Student Comments
Chose mode 1.
Continued to Year 2.

FISH DECREASE IN MARCH
1
FISH DECREASE MAY BE DUE TO LIGHT DECREASING DURING YEAR 3
2
FISH DECREASE MAY BE DUE TO SPawning 4
MISCONCEPTION
MISCONCEPTION

OUTPUT OF DATA
INPUT TO CONTINUE TO 2ND YEAR
S. 2nd YEAR
FISH DECREASE IN MARCH
FISH DECREASE MAY BE DUE TO LIGHT DECREASING DURING YEAR 3
FISH DECREASE MAY BE DUE TO SPawning 4
MISCONCEPTION
MISCONCEPTION

ALL POPULATIONS RELATED
MISCONCEPTION
MISCONCEPTION

The interesting part of this extract of W's observation protocol is shown below:
The formation of a concept, according to Peirce's Theory, occurs following the perception of surprising data. In this example, the surprising data is a decrease in the number of fish in March (comment 1). After having made this perception, MW put forward two hypotheses which she thought might be reasonable explanations. The first, that the decrease may be due to spawning (comment 2) was not apparently acceptable since a second hypothesis was put forward, that the decrease may be due to a light decrease during the year (comment 3). The latter concept was probably put forward as reasonable because she saw the fish relying on other populations in the pond ecosystem which were dependent on light (e.g. phytoplankton). Comment 4 appears to substantiate this supposition. In fact, the acceptable concept (comment 3) is used here as evidence supporting a hypothesis represented by comment 4, and is an example of a type D form of concept learning, or a hypothetico-deductive form of concept learning.

**Type B Concept Learning** (Figure 9.1.b)

In this form of concept learning, the individual using the CAL simulation can be regarded as an actor directly involved in the ensuing episode. The individual manipulates the simulation model by a variation of its INPUT parameters and, as a consequence, the behaviour changes in a way which is perceived as being caused by that manipulation. That is, the action A (the change in parameter variables) causes an event B.
Example 1: (JH2: PONDGAME)

<table>
<thead>
<tr>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT 60 phytoplankton</td>
<td>Exclaimed when saw the phytoplankton increase dramatically in numbers in November.</td>
</tr>
<tr>
<td>50 herbivores</td>
<td>If the pollution is the same, and the phytoplankton increased last year because of the pollutant, probably because the fish knocked out...</td>
</tr>
<tr>
<td>900 fish</td>
<td>seems peculiar.</td>
</tr>
<tr>
<td>2% fish for sale</td>
<td></td>
</tr>
<tr>
<td>No fishing</td>
<td></td>
</tr>
<tr>
<td>Low level of pollution in October</td>
<td></td>
</tr>
</tbody>
</table>

To explain this learning episode requires some assumptions to be made. The surprising event was the dramatic increase in plankton in November (the exclamation, comment 1). Comments 2 and 3 appear to provide two alternative conceptions which can explain the increase in plankton.

Comment 2, "the phytoplankton increased last year because of the pollutant", might be taken to mean that the pollutant had a direct action on the plankton causing a growth explosion. However, comment 3, "...probably because the fish knocked out", provides a somewhat different interpretation. Comment 3 implies that:

i) the pollutant "knocked the fish out" (killed the fish),

ii) and that the plankton increased in numbers because there were no fish (to act as predators?). Quite soon after making comment 3, JH2 said "...the fish need the phytoplankton" which would tend to support this assumption.

My interpretation of this episode can be represented diagrammatically thus:

- 353 -
Concept (a) is formed as a result of seeing that pollution, one of the INPUT variables, has killed the fish, and is thus an example of a type B form of concept learning.
Example 2: (DC: POND2HELP)

<table>
<thead>
<tr>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT a moderate level of pollution in May.</td>
<td>Great drop in others. Obviously not more.... Plankton overrun everything else. Plankton got back to reasonable numbers, and herbivores. The fish are completely killed off. Must have initially killed the herbivores so plankton increased and fish couldn't feed on herbivores so died out completely.</td>
</tr>
</tbody>
</table>

To understand more completely what DC was saying here, the OUTPUT he obtained at this point in the program run is displayed below:

<table>
<thead>
<tr>
<th>MONTH</th>
<th>PHYTOPLANKTON</th>
<th>HERBIVORES</th>
<th>FISH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(x 10^9)</td>
<td>(x 10^6)</td>
<td></td>
</tr>
<tr>
<td>JAN</td>
<td>103</td>
<td>26</td>
<td>797</td>
</tr>
<tr>
<td>FEB</td>
<td>287</td>
<td>25</td>
<td>782</td>
</tr>
<tr>
<td>MARCH</td>
<td>348</td>
<td>55</td>
<td>673</td>
</tr>
<tr>
<td>APRIL</td>
<td>263</td>
<td>55</td>
<td>1525</td>
</tr>
<tr>
<td>MAY</td>
<td>7414</td>
<td>7</td>
<td>91</td>
</tr>
<tr>
<td>JUNE</td>
<td>77097</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>JULY</td>
<td>2541</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>AUG</td>
<td>272</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>SEPT</td>
<td>258</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>OCT</td>
<td>208</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>NOV</td>
<td>236</td>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>DEC</td>
<td>251</td>
<td>32</td>
<td>0</td>
</tr>
</tbody>
</table>

Comment 1 refers to the vast increase in phytoplankton numbers that commenced during May, the month of the pollution, and reached its maximum in June. When DC said "Must have initially killed the herbivores" (comment 3), I think that he was referring to the vast decrease in numbers from 55 x 10^6 to 1 x 10^6 rather than to an extinction of that population, as happened to the fish population. This learning episode can be represented thus:
In making comment 3, DC demonstrated a type B concept formation, relating the INPUT data to what happened in the OUTPUT data.

**Type C Concept Learning** (Figure 9.1.c)

This form of concept learning differs from the previous one only in that one event perceived in the OUTPUT data is related to a second event also perceived in the OUTPUT data. The first event is seen as the cause of the second.
Example 1: (AB: PONDQU)

<table>
<thead>
<tr>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT a high level of pollution in</td>
<td>From the year before you've got an increase in phytoplankton which increases up</td>
</tr>
<tr>
<td>August</td>
<td>to May when the herbivores come into the pond. From then, increase in herbivores,</td>
</tr>
<tr>
<td></td>
<td>which causes a decrease in the phytoplankton throughout the rest of the year...</td>
</tr>
<tr>
<td>Continued to year 2</td>
<td></td>
</tr>
</tbody>
</table>

The part of this observation protocol relevant here can be represented diagrammatically thus:

```
INPUT TO CONTINUE TO YEAR 2

OUTPUT OF DATA

INCREASE IN HERBIVORES

DECREASE IN PLANKTON

HERBIVORE INCREASE CAUSES PLANKTON DECREASE
```
Example 2: (AY: PONDGAME)

This example of concept formation can be shown easily just using a diagram representing the episode:

![Diagram of concept formation](image)

The concept formed, that "plankton and herbivores are independent of the fish", is reasonable when the two former populations survive without the latter. It is a valid concept to form in terms of the concept "food pyramid" since populations in the food pyramid, such as are plankton and herbivores, are only dependent on populations lower in the pyramid, not on those higher in the pyramid, as are the fish.
Type D Concept Learning (Figure 9.1.d)

Unlike the three previous types of concept learning, this method is one in which previously formed concepts are tested to determine whether it is applicable, or valid, in the context of the simulation model. In other words, it is a hypothetico-deductive method of concept learning. It is a method by which an individual is able to discover both positive and negative exemplars of a concept; to discover that the concept is applicable in some situations, and that another concept is necessary for other situations. I have previously indicated that I believe that this is not a method by which concepts are formed, but a method by which a concept is broadened.
Example 1: (AR: PONDQU)

The following diagrammatic representation of part of AR's program run is one in which the "pond" is polluted at a high level killing all the pond organisms. Within several months the plankton reappear in the pond. This is soon followed by the reappearance of the herbivores:

The fact that plankton reappeared before the herbivores appears to confirm the student's concept that herbivores feed on plankton. If the herbivores had reappeared before the plankton it would have meant that they need not, or did not, feed on the plankton.
Example 2: (PS: POND-2)

<table>
<thead>
<tr>
<th>Student Action</th>
<th>Student Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>INPUT a moderate level of pollution in September.</td>
<td>I am going to see if the numbers build up, and then drop off because of the pollution. It kills all the fish. The number of phytoplankton increases probably because the amount of oxygen in the water. The fish don't take any oxygen so the phytoplankton increase.</td>
</tr>
</tbody>
</table>

The diagrammatic representation of this part of PS's protocol is shown below:

![Diagram](image)

Two hypotheses appear to be confirmed in this learning episode. The first is that the plankton increase occurs because of an increase in oxygen because the fish don't use it (comment 2). The second is that fish are confirmed as using oxygen because the plankton increased.
9.2.3 The Effect of Program Structure on Concept Learning

Each of the four types of concept formation described in 9.2.2 are distinct in terms of the behaviour being exhibited. It would not be unreasonable to assume, therefore, that the way by which the simulation is presented might affect the proportion of cognitive activities promoted by each of the POND programs. The protocols of the students' program runs were analysed to determine the frequency of each type of concept formation activity, the results of which are shown in figure 9.3.

<table>
<thead>
<tr>
<th>Type of concept learning</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAL Program</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POND-2</td>
<td>27.4</td>
<td>20.5</td>
<td>34.8</td>
<td>17.4</td>
</tr>
<tr>
<td>PONDQU</td>
<td>26.6</td>
<td>19.4</td>
<td>25.3</td>
<td>28.7</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>8.1</td>
<td>15.2</td>
<td>32.8</td>
<td>44.0</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>17.4</td>
<td>9.1</td>
<td>59.8</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Figure 9.3 Proportion of Concept Learning Activities Encouraged by the POND Programs

Differences in the proportion of concept learning activities encouraged by the POND programs were determined by the Student t-test and are shown in figure 9.4. Values exhibiting greater than 90% significance
were chosen as those indicating an effect of program structure on the form of concept learning.

<table>
<thead>
<tr>
<th>Program</th>
<th>Type of concept learning</th>
<th>PONDQU</th>
<th>PONDGAME</th>
<th>POND2HELP</th>
</tr>
</thead>
<tbody>
<tr>
<td>POND-2</td>
<td>A</td>
<td>0.062</td>
<td>2.533 (+)</td>
<td>1.224</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.087</td>
<td>0.534</td>
<td>1.471</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.863</td>
<td>0.175</td>
<td>2.234 (+)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>1.364</td>
<td>1.940 (+)</td>
<td>0.567</td>
</tr>
<tr>
<td>PONDQU</td>
<td>A</td>
<td>1.459</td>
<td></td>
<td>0.795</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.307</td>
<td></td>
<td>0.933</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>0.605</td>
<td></td>
<td>2.948 (+)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>1.092</td>
<td></td>
<td>1.956 (+)</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>A</td>
<td></td>
<td></td>
<td>1.359</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td>0.726</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td></td>
<td></td>
<td>2.157 (+)</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td></td>
<td></td>
<td>2.443 (+)</td>
</tr>
</tbody>
</table>

"+" = significant at 90% level
(N= : POND-2 = 8; PONDQU = 9; PONDGAME = 7; POND2HELP = 10)

Figure 9.4 A comparison of types of concept learning encouraged by the POND programs

In chapter 8 I demonstrated a somewhat wider range of cognitive effects that program structure can have on cognitive activity. I showed some of the correlations that appear to exist between certain of these cognitive activities. Figure 9.5 shows the correlation coefficients between what I regard as the major cognitive activities and these forms of concept learning demonstrated by all of the students using the POND programs.


<table>
<thead>
<tr>
<th>POND program</th>
<th>POND-2</th>
<th>PONDQU</th>
<th>PONDGAME</th>
<th>POND2 HELP</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept learning activity</td>
<td>A·B·C·D</td>
<td>A·B·C·D</td>
<td>A·B·C·D</td>
<td>A·B·C·D</td>
<td>A·B·C·D</td>
</tr>
<tr>
<td>No. preconceptions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. INPUTs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. observations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. expltl. activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

"+" = greater than 95% level of significance

Figure 9.5 Correlations between the number of each type of concept learning activity and other major cognitive activities

<table>
<thead>
<tr>
<th>Type of concept learning activity</th>
<th>Mean number of concept learning activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>N =</td>
<td>8</td>
</tr>
<tr>
<td>POND-2</td>
<td>3.0</td>
</tr>
<tr>
<td>PONDQU</td>
<td>1.2</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>1.0</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Figure 9.6 Mean number of concept learning activities demonstrated by students using the POND programs
Figure 9.7  Table showing significant differences between the mean number of concept learning activities for each of the POND programs

The data in figures 9.3 to 9.7 (inclusive) show how the proportion of concept learning activities (9.3, 9.4) and the number of concept learning activities (9.5, 9.6, and 9.7) are affected by program structure. Program structure will not only affect concept learning "in toto" and the particular types of concept learning demonstrated, but will also affect (as I showed in chapter 8) other cognitive factors and activities. These cognitive factors and activities take various forms, but the most important for concept learning and CAL are probably the number of relevant concepts the person brings to the learning situation, the number of sets of data that are INPUT, the number of
observations that are made, and the number of experimental activities
exhibited. These four factors have been correlated with the various
types of conceptual learning exhibited by the students using the four
POND programs (figure 8.5).

9.2.3.1 POND-2: This is the original POND program from which the
other three POND programs were developed. It is, in many ways a
"normal" type of science CAL program consisting of a number of
different modes which the students are free to investigate. The
program does not contain any "helpful" information to aid the learning
process, this being left to the package notes (not available to the
students in these studies).

I have already shown (8.4.1) that the structure of this program
encourages the person using it who has little knowledge of the food
pyramid concept to experiment with the simulation, to hypothesise about
how the ecosystem model is behaving, to INPUT a relatively large number
of sets of data, to make a relatively large number of observation
statements, and to form (or at least demonstrate) a relatively large
number of valid concepts.

Figure 9.3 shows that students using POND-2 are likely to learn most
concepts by method C, and least likely by method D. However, concepts
are learnt fairly evenly by each of the four methods as figure 9.8
shows.
Figure 9.8 Pie-chart showing the proportion of concepts learnt by each type of concept learning for POND-2

Figure 9.5 shows that it is difficult to attempt to relate various cognitive factors and activities, regarded as of importance, to the form of concept learning exhibited. Concept learning using POND-2 appears to be influenced largely by the observations made of the behaviour of the simulation model.
9.2.3.2 PONDQU: This program differs from POND-2 in that it poses questions concerned with the important concepts within the model to the students. Each of the four modes of the program has these questions, but their form differs between the modes. The questions asked in modes 1 and 2 requires the individual using the program to reply to the question, and poses other questions if a wrong answer is provided. The questions are expected to result in an immediate and observable change in conceptual beliefs exhibited, for the same reasons as programmed learning was expected to result in a given conceptual structure.

I have shown (8.4.2) that students using this program appear to most successful if they employ various strategic actions and put forward hypotheses to explain the OUTPUT data. Using such a cognitive style the student seems to make a relatively large number of observation statements and demonstrate a relatively large number of valid concepts.

PONDQU seems to encourage less concepts to be formed than any of the other three POND programs; all four types of concept learning appear to be equal in this respect (figure 9.9).
The provision of questions, whose purpose is to change, if necessary, an individual's conceptual structure, thus seems to inhibit learning. Such an inhibition may arise from the "spoonfeeding" exercise. To be provided with the central concepts of the simulation model appears to take away the individual's motivation to learn.

If the structure of the program does inhibit an individual's motivation to learn, it is not apparent in the length of time that the students used this program. There was no significant difference between the lengths of time the program was used.
"Spoonfeeding" may lead to an acceptance, by the students, of the concepts that they are taught explicitly by the program. One student (JB), for example, described a food pyramid as:

"...a series of rectangles of different lengths with the smaller on the top and the largest on the bottom showing a need for food by the various animals."

She had not correctly understood what the diagrams in the question had been attempting to show her. She had taken each rectangle to represent a "need for food" rather than representing the number of individuals in a particular population.

Another student (SW) said she would have liked more questions in the program. However, of the five students who were asked whether they had found the questions useful, two had not done so.

My aim in providing these questions had been to encourage users of the program, if necessary, to think about the simulation under the direction of the questions, and then to go back and find out whether the data they were being provided with would support these concepts. In very few instances was there an observable response by an individual to alter what they were doing and subsequently determine whether the simulation model was conceptually in agreement with the concepts being conveyed by the questions. One student (SW) said he would have preferred to have been provided with questions that told him to go back and reinvestigate part of the simulation.
This form of questioning, involving a branched loop in the program, is ineffective in that it inhibits meaningful learning. To be passively "indoctrinated" does not necessarily lead to meaningful learning, and, as I have showed, fewer concepts are demonstrated by users of this type of program.

9.2.3.3 PONDGAME: A game form of CAL simulation, as I showed in 8.4.3, encourages a large number of strategic actions and the formation of a higher number of valid concepts than the other three POND programs. The highest number of concepts were formed by methods C and D (see figures 9.6 and 9.10). PONDGAME encourages a significantly higher number of type D concepts than the other three POND programs (see figure 9.7).
These findings are not surprising since the program is a game, and games are intended to encourage strategic decisions, hypothesis formation and testing.

The relatively high proportion of concepts formed by method C probably arises from the complex nature of the INPUT data. Causality of events is thus more likely to be related to events perceived than those initiated (through the INPUT of data) by the individual. Once hypotheses are formed, they are tested. This is obviously encouraged by the "will to win" of an individual. If a person is to win, then their hypotheses should be correct hypotheses. Hypotheses are shown to be correct or incorrect by the person making a profit for the fish farm being modelled by this program.
9.2.3.4 POND2HELP: In many ways, this program encourages a similar series of cognitive events as does POND-2 (8.4.1). There is, however, a difference in the proportion of concepts formed by each of the methods, as figure 9.11 shows.

![Pie chart showing the proportion of concepts learnt by each type of concept learning for POND2HELP](image)

**Figure 9.11** Pie-chart showing the proportion of concepts learnt by each type of concept learning for POND2HELP

There is a high proportion of concepts formed by method C, which is significantly higher than for the other three POND programs (figure 9.4). In fact, there is a high positive correlation (figure 9.5) between this form of concept learning and the number of INPUTs, observation statements and experimental activities.

The difference between this and the POND-2 program exists in the questions which are answered whenever the student does not want to
"continue", and the help which can be provided on request by the student and based on the answers to the questions.

Even though the student does not know whether he has answered a question correctly, these questions might direct students to think in a certain way or to investigate a particular mode of the simulation program as the following quotations from interviews show:

"I: Had you realised they were in equilibrium?
MB: Well, when it came out with those questions all about it, yes."

"SB: They were good pointers for further experiments...direct questions like: "Did the pollution affect the pond?" which other more leading questions such as "Did the...fish feed on the plankton and herbivores?"

"FQ: Because of the questions I then went and chose the pollution and saw what happened when I had different numbers because they do poke you in the right direction."

Of the nine students who used this program and were asked whether the questions had been of use, there was not one student who said that they had not been useful. Three students had said that they were uncertain, but felt that they might have been useful:

"They helped more than they hindered."
(DH)

"I think they might have, but I didn't particularly find them."
(NL)

The help, on the other hand, is less extensively utilised by those using the program. Help will only be offered after the third question-answering session, and not everyone will feel that they need to receive any help:
"I: Why didn't you ever ask for help?
PQ: I don't think I got stuck."

Four students found the help useful, at least to some extent; three students did not. The help can cause a change in understanding:

"It has a debate with you...same way as a teacher does...It can counteract your ideas. If you say that fish float or something on the water, something silly like that, it can debate...That's when the information helps there. It can...push your view one way or the other."

(DH)

"I asked the computer for help, you gave me examples of an experiment to do. Then I realised that my views before started wrong, and I had to change them."

(RC2)

It thus seems that both the questions and the help, if provided, can help the students to look at what is happening. They can direct student thinking and the observations that they make. It might be that they act as provided, rather than intuitively created, hypotheses which encourage students to have an alternative epistemic tube.

Through this alternative epistemic tube, event pairs might be seen from which concepts are formed (by method C).

If these questions and the help do provide hypotheses, it could be said that we should expect a high proportion of concepts to be formed by the hypothetico-deductive method (method D). However, this does not seem to be the case. What seems to be happening is the student comes to realise that their concept, if different from the concept implied in the question or help given, might not be a satisfactory one. The student might then feel that they ought to look for an alternative, more fruitful one. Their observations may be guided and thus lead to the formation or acceptance of the concept implicit in the question or help. Their observations may not be directly involved with proving that the implicit concept is correct. The following quotations tend
to show that the students are not testing provided hypotheses, but their epistemic tube had been changed by the question or the help provided.

"I realised that my views before started wrong, and I had to change them...The phytoplankton equilibrium with the rest, couldn't reach an equilibrium...later on I realised they could."

(RC2)

"I think it was one of the suggestions made...It seemed quite interesting to see the effect, I don't know quite what I thought it would be, but interesting to see."

(DC)

Sometimes, as the previous quotations indicate, ideas for a different approach for using the program are encouraged. This may account for the correlation between type C concept formation and experimentation by the students, the number of sets of data INPUT, and the number of observation statements made.
9.3 Alternative Conceptions and Misconceptions

Whenever a student undertakes a learning program under the direction of a teacher, there is a particular body of knowledge and meaning which the teacher would like the student to assimilate. CAL is no different from this general notion of the didactic approach to teaching. CAL programs contain a model from which the student can gain an insight into the "real world".

However, even with the most careful of program designs I doubt whether individuals using a CAL program will gain, at the first attempt of designing the program, the "true" conceptions entailed within the simulation model. The program user will often form alternative conceptions to those the program designer would have wished.

It is only by understanding how these alternative conceptions, or misconceptions in terms of the simulation model, arise that some improvement in the design of CAL programs can, in part, be made.
Misconceptions often occur because of a lack of thought. A student might fail to consider all of the relevant information when forming a concept, their epistemic tube may not be far reaching enough because, for example, of a lack of suitable experience in that subject area. However, how is a student to know what that relevant information is? The relevant information may, in part, be the context within which the behaviour of the model is observed; it may be because certain event pairs are mistakenly related by a causal statement; it may be the perception of inaccurate observational data (perhaps due to a poor graphical display); it may be because the individual perceives the behaviour of the simulation model through an "epistemic tube" dictated by an inappropriate body of knowledge, by inappropriate conceptions.

9.3.1 Student Conceptions of the Concepts "Phytoplankton" and "Herbivore"

The concepts "phytoplankton" and "herbivore" are important conceptions for those using the POND programs. It is only from a full understanding of these concepts that the students should be able to form the concept "food pyramid".

Phytoplankton and herbivores are two of the three populations in the simulated pond ecosystem. The third population is that of the fish. Program users should find less difficulty with the latter concept than with the two concepts being considered here. The concept "fish" is one encountered in everyday life, it is a concept that should be part of their "lay science". Unlike fish, the concepts "phytoplankton" and
"herbivores" will, in all probability, not be part of a person's "lay science". Individuals may not be able to define what they understand by these terms, nor to provide examples of them.

Students taking part in these studies were not provided with any information that would have increased their understanding of the simulation model prior to their use of a POND program. However, the authors of POND-2 (Tranter and Leveridge, 1978) provided extensive package notes which they expected students to study before using the program.

9.3.1.1 The Concept "Phytoplankton"

Phytoplankton are microscopic plant life, e.g. algae, in the pond ecosystem. Indeed, in the simulation model used in the POND programs, it is the only form of plant life. They are the "producers" of the ecosystem, photosynthesising and producing a variety of carbohydrates, proteins and lipids.

Figure 9.12 is a summary of the replies obtained from 30 students to the question "What are phytoplankton?". Some students' answers included several categories in the list:
Figure 9.12 Table summarising student conceptions of "Phytoplankton"

<table>
<thead>
<tr>
<th>concept description</th>
<th>frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Don't know</td>
<td>3</td>
</tr>
<tr>
<td>b) Plants</td>
<td>9</td>
</tr>
<tr>
<td>c) Micro-organisms</td>
<td>5</td>
</tr>
<tr>
<td>d) Algae</td>
<td>7</td>
</tr>
<tr>
<td>e) Spirogyra</td>
<td>1</td>
</tr>
<tr>
<td>f) Animals</td>
<td>4</td>
</tr>
<tr>
<td>g) Unicellular animals</td>
<td>5</td>
</tr>
<tr>
<td>h) Photosynthetic animals</td>
<td>2</td>
</tr>
<tr>
<td>i) Worms, larvae</td>
<td>4</td>
</tr>
</tbody>
</table>

Concepts b – e are acceptable concepts ("micro-organisms" is only acceptable if they are considered to be photosynthetic, not if they are saprophytic bacteria). Concepts f – i are incorrect conceptions probably arising from the more familiar (?) concept "zooplankton". Examples of correct conceptions demonstrated by students are:

"...small form of plant life." (ST: POND-2)
"...algae" (PN: POND-2)

However, the concept often appears with the concept of zooplankton, thus the concept being demonstrated was that of "plankton" rather than anything more specific.
"Some could photosynthesise. Small sorts of things like Amoeba-shaped things. They can engulf food."
(MB: POND2HELP)

"Plants. Like...Spirogyra. Unicellular animals."
(SW: PONDQU)

"...in the sea it's plankton and krill...all the tiny little organisms that the animals in the sea depend on for their nutrition. Bugs and bacteria and larvae...Algae and related micro-organisms."
(FQ: PONDHELP)

The final group are those organisms which many lay people would probably see as the "basic" source of food in a pond, lake or the sea, the microscopic animals, the zooplankton. Some of the students seemed to know that the start of the food chain must be photosynthetic, and thus their concept of phytoplankton is that of zooplankton, but photosynthetic zooplankton!

"Animals (but photosynthetic)"
(SH2: PONDQU)

"Micro-organisms (animal - can be photosynthetic)"
(RC1: PONDGAME)

There are those students who see them only as animals.

"Single-celled animals"
(JH1: PONDQU)

"Not plants"
(SDT: PONDHELP)

9.3.1.2 The Concept "Herbivore"

Herbivores are animals which eat plants. In the simulated pond ecosystem they are not a particular type of animal, but are a group of animals feeding on the phytoplankton. They may be single-celled protozoans or multi-celled animals such as snails.

Figure 9.13 is a summary of the replies I obtained from 23 students to
the question "What are herbivores?". Some students' answers included several categories in the following list:

<table>
<thead>
<tr>
<th>concept description</th>
<th>frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Don't know</td>
<td>3</td>
</tr>
<tr>
<td>b) Eat plants</td>
<td>6</td>
</tr>
<tr>
<td>c) Animals</td>
<td>3</td>
</tr>
<tr>
<td>d) Snails</td>
<td>5</td>
</tr>
<tr>
<td>e) Crustaceans, molluscs</td>
<td>2</td>
</tr>
<tr>
<td>f) Newts, frogs</td>
<td>1</td>
</tr>
<tr>
<td>g) Daphnia</td>
<td>2</td>
</tr>
<tr>
<td>h) Flatworms, worms</td>
<td>2</td>
</tr>
<tr>
<td>i) Protozoa</td>
<td>2</td>
</tr>
<tr>
<td>j) Arthropods</td>
<td>1</td>
</tr>
<tr>
<td>k) Insects</td>
<td>1</td>
</tr>
<tr>
<td>l) Animals around the pond</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 9.13 Table summarising student conceptions of "Herbivores"

The only category where there is an obvious difficulty in the students extending what they have learnt about herbivores in the past to the context of the simulated pond ecosystem, is where the herbivores are seen as plant-eating animals around the pond rather than in the pond. For example:

"Birds, voles, shrews"  
(JB: PONDQU)

"Feed on plants. Do not actually live in the water, but feed from the water."

(PP: POND2HELP)

"Feed on grass, for example, sheep."

(DH: POND2HELP)
Because the concept "herbivore" is more familiar, of use in everyday language, than the concept "phytoplankton", it is not surprising that the students had less difficulty extending the concept to the context of the pond. However, the students did have more difficulty in identifying the animals which they imagined the pond herbivores to be. Only 11 of the 23 students who were asked what they understood by the word herbivore, gave a specific example of a pond organism.

9.3.1.3 Implications for the Design of CAL Programs

The students' progress with the POND programs would have been inhibited by not knowing the concepts "phytoplankton" and "herbivore", especially the former. It may have meant the difference between the use of the POND programs being a meaningful and enriching experience as opposed to a meaningless one.

It is here that the package notes, if read by the students, would have provided the necessary background information for these concepts to be understood. It is necessary for students to eventually understand these concepts, and preferably this should be encouraged at an early stage during program use to allow a full investigation of the model. The questions posed in PONDQU and POND2HELP help achieve this aim.
9.3.2 Student Misconceptions of the Pond Ecosystem

In 9.2.2 I proposed four forms of concept learning. These four forms of concept formation are relevant to the formation of valid concepts, but also to the formation of invalid concepts.

In Type A concept formation (figure 9.1.a), the creation of a hypothesis to explain an observed event where there is no obvious cause, can easily lead to the formation of a misconception. The second example I chose to illustrate Type A concept formation (that of MW: POND-2) is just an example. These hypotheses are created by intuition, and should be either eventually shown to be valid or they should be rejected as invalid. At the time of their formation, however, if invalid they must be regarded as misconceptions.

In Type B concept formation (figure 9.1.b), an action (the INPUT of a particular set of data) is perceived as the cause of a perceived event; in reality it is not. The following diagrammatic representation of part of a student's program run shows just this sort of misconception taking place:
(JH2: PONDGAME)

In this episode, the most important factor for the student was the absence of the plankton from the pond. The initial number of herbivores and fish in the pond were the maximum possible. Both of these populations became extinct, and were attributed to the plankton being the source of food for both populations.

In the case of the herbivores this is the valid concept to hold. However, to extend the concept to the fish is the result of a misconception. In this case, the demonstration of Type C concept formation was necessary, that is, to relate the extinction of the fish population to that of the herbivores by saying that the fish are dependent on herbivores as a source of food. However, many of the students taking part in these studies held the view, from previous experiences, that fish fed on the plankton. This student (JH2) did, in fact, hold this view. A little earlier he had said that the:

"I've got a view of the phytoplankton. I regard them as a food source..."
Type C concept formation (figure 9.1.c) takes place when certain perceived events are related by a causal statement, the first perceived event being the cause of the second. Certain perceived event-pairs are, however, coincidental. To relate coincidental events, events merely close to one another in time, will lead to the formation of misconceptions, as in the following examples:

\[\text{INPUT \ 200 \ PLANKTON, 25 HERBIVORES, 550 FISH} \rightarrow \text{OUTPUT OF DATA} \rightarrow \text{PLANKTON DECREASE} \rightarrow \text{FISH DECREASE} \rightarrow \text{FISH DEPEND ON PLANKTON AS A SOURCE OF FOOD} \rightarrow \text{MISCONCEPTION}\]

\[\text{FISH DEPEND ON PLAN KTON AS A SOURCE OF FOOD} \rightarrow \text{MISCONCEPTION}\]
In both of these examples, it seems that the chronological order in which the observations were made controls the concept that is formed. In the first of these two examples, the student (PS) sees what, in all probability, are seasonal fluctuations of the plankton and fish populations as being related in another way — by the fish feeding on the phytoplankton. In the second of these two examples, where the same observations as the first example were made but in the opposite order, DW created a novel explanation for the plankton decrease by saying that they feed on the fish excreta. From his present knowledge he would have probably realised that plankton are too small to eat fish, or fish normally eat small organisms like plankton. Therefore, for the fish decrease to cause a decrease in the plankton, the explanation could not involve a direct feeding relationship.

By holding particular concepts which are mistakenly seen as applicable to certain perceived events, misconceptions will arise. Type D concept formation can thus show the acceptance of invalid concepts, as in the following example:
When observing an ecosystem, one of the most obvious effects on the size of the various populations is the effect of the weather, the seasons, the environmental temperature. The seasonal variation in population numbers and the annual cyclicity of the seasonal variation tend to be obvious from everyday experiences. When, therefore, as in this episode, the population numbers are seen to decrease, the obvious reason is the "weather". In this case, however, it was the effect of the pollutant, not the weather. This the student realised when all the populations died! Normal weather conditions would not have this effect! The perception of this surprising event caused the acceptance of the valid concept and the rejection of the misconception.

These types of...

...misconceptions are not too serious if the structure of the CAL program encourages the student to fully investigate the simulation model, and to question what they are seeing. In time, the correct conceptual structure will develop.

In some instances, to be left with misconceptions, for example, that fish feed on phytoplankton rather than on herbivores, will not leave the students at an educational disadvantage, for it is a concept that is valid in certain real-world contexts. However, as an educational tool, to be left with a misconception means that the CAL program has, in part, failed. Students have not been encouraged to investigate the model thoroughly enough, or the model has not been described in unambiguous mathematical terms, or the program does not allow a thorough investigation of its characteristics.
In addition to the above, I think that one of the worst characteristics of a poor CAL program is to be found in the graphical display of the OUTPUT data.

The OUTPUT data by a CAL program is the sense data from which an individual can perceive events. If the design of the graphical display is poor, of low resolution, then incorrect perceptions can take place from which misconceptions will often be formed. Students using the POND programs frequently exhibited incorrect observations, some of which were due to a poor quality graphical display, but some were due to an existing conceptual belief affecting what that individual perceived (dictated the bounds of their epistemic tube).

An example of this theory-based perception of data was seen in the use of POND-2 by PS. When he came to use mode 3 of the program, that is fishing the pond, he INPUT the following variables:

10 fishermen each fishing twice a month,

A close season from March to June (inclusive),

A tabular output of the data,

The data output was as in the following table:
Following the OUTPUT of these results he said:

"In the close season, the number of fish increases. The number of phytoplankton decreases when the number of fish decreases. Fishing definitely decreases the number of fish as well as the number of phytoplankton."

If a relationship were to exist between the fish and plankton as indicated in comment (1), I would not only expect the plankton to decrease when the fish decrease, but the plankton to increase when the fish increase. This relationship between the fish and the plankton does not exist in the simulation model and nor does the data OUTPUT support this concept. A more careful analysis of the data by the student would have made this apparent, for example between January and March the plankton numbers increase whilst the number of fish decreases.

The increase and decrease in population sizes of all three trophic levels (fish, herbivores and phytoplankton) follows a similar, but not identical, annual, or seasonal, pattern. It is this concept of seasonal variation which seems to confuse some of the students,
including PS. It is only by careful examination of the data that the more subtle interrelationships might be seen. It is far easier to determine these interrelationships through scientifically designed experiments.

It is thus apparent that students do not necessarily look at information in the same way as a subject-matter expert would, or as a subject-matter expert would like the student to look at the information that is presented.

The program developer should provide a simulation model which has the potential to enable a person to explore the model and experience its behaviour.

It should, therefore, be possible for an individual to receive a particular "package of knowledge". In other words, many program developers would expect the knowledge an individual, a student, to acquire to be the "knowledge-as-presented" by the CAL program.

However, as I have shown here, we must not assume that the "knowledge-as-conceived" by the student will be the same as the "knowledge-as-presented" by the program. Preconceptions, a lack of experimental and problem-solving skills, poor observation techniques can all affect the final result of the learning experience. The program developer must try to present information to students in a manner which will facilitate the learning of the valid concepts implicit in the simulation model.
If we accept that students will form invalid concepts, for the reasons given above, then the CAL program should encourage an exchange of those invalid concepts for the valid ones. Students should, therefore, be encouraged or motivated to use a program for as long as it is necessary for this conceptual exchange to take place. Game versions of programs and the form of questioning and provision of help used in POND2HELP are both ways by which students can be encouraged to use the program for as long as is necessary. The game version with the overt indication of either knowing or not knowing the valid concepts to be able to control the model, may be better than the method used in POND2HELP in this respect.

POND2HELP, and PONDQU, are versions of the POND program which rely on another strategy for attempting to encourage the formation of valid concepts. PONDQU and POND2HELP, especially the latter, attempt to encourage a hierarchical, or "progressive", acquisition of concepts.

The hierarchical acquisition of concepts has been considered in chapter 7. Conceptual exchange will be considered in the next chapter of this dissertation.
Chapter 10

CAL and Concept Learning as a Scientific Exercise

10.1 Introduction

If CAL simulation programs are to act as substitutes for laboratory based exercises, then they should be capable of conveying the appropriate information to the students. In addition, they should also encourage similar cognitive activities to those which would have been demonstrated in the science laboratory, that is, those concerned with the various aspects of scientific thought.

When students who participated in these studies were asked if they believe they experiment or act scientifically their answers indicate that their notion of a "scientific" experiment is simple. They see, for example, "just seeing what happens" and "see what the difference would be" as acting scientifically. This is similar to the findings of Swift (1981) who reports younger pupils seeing part of scientific method being singular activities such as "measurement" and "calculation". Rigorous, controlled experiments do not always seem to be necessarily included in their notion of a scientific exercise, at least as it is applied to the use of a CAL program. But, are the students using the CAL programs in a scientific manner?
Much of science is concerned with the formation and testing of hypotheses. Science can be regarded as a special form of cognition. Concepts are often regarded as hypotheses which can be exchanged or modified if found to be unsuitable. Science involves the application of rigour and objectivity to these processes. Peirce's Theory of Abduction is concerned with the factors which are involved with the creation and adoption of hypotheses (concepts).

Abduction, the process of creating and adopting a "reasonable" hypothesis, is initiated by an individual seeing a surprising fact. A fact or event is surprising because it apparently cannot be explained using a person's existing conceptual structure. In other words, the data appears to be anomalous. On seeing such data, a person can be said to be acting "scientifically" according to Peirce if they create a reasonable explanation for that observation, deduce the consequences of that explanation and then test them experimentally. I will analyse the way in which thee students participating in these studies used the POND programs to see whether their cognitive activities can be said to conform to this notion of scientific methodology.
10.2 On Seeing Surprising Data - The Nature of Conceptual Learning

Much of the time during a CAL program run is spent by the students making observations and describing what is happening. Much of what they see they regard as acceptable. Using the POND programs they can learn how the populations interrelate and thus gain an insight into the behaviour of a pond ecosystem. However, only a small proportion of what they perceive appears to conform to the description of being "surprising" (see figure 10.2).

From the protocols and interview transcripts of all the students who used the POND programs I determined the total number of observations (O) each made and the number of observations which appeared to conform to the notion of being surprising data (S) throughout their program run. I then tried to ascertain how each item of surprising data was treated, that is, the events that followed it as a direct result of the observation being found to be surprising.
<table>
<thead>
<tr>
<th>Program</th>
<th>N</th>
<th>Number of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>POND-2</td>
<td>9</td>
<td>21 26 2 0 0 1 0 0 1 1</td>
</tr>
<tr>
<td>PONDQU</td>
<td>9</td>
<td>11 9 1 0 2 0 0 0 0 0</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>7</td>
<td>18 17 1 3 3 1 0 0 0 0</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>10</td>
<td>31 17 0 1 1 0 1 1 0 0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>35</td>
<td>81 69 4 4 6 2 1 1 1 1</td>
</tr>
</tbody>
</table>

* Event pattern

a: S
b: S—→ H
c: S—→ H—→ O
d: S→ H₁—→ O(S)→ H₂
e: S→ H₁—→ O(S)→ H₂→ O
f: S—→ H₁

H = hypothesis; D = deduction; I = induction; O = observation
S = surprising data

Figure 10.2 Frequency of events following the perception of "surprising data" for all students using the POND programs

Figure 10.2 shows that very few instances following the perception of surprising data will initiate the whole scientific process of abduction, deduction and induction. Of the 170 instances reported here of events regarded by the students as anomalous, 89 (52%) resulted in the initiation of a reasonable explanation. By a "reasonable"
explanation I mean that the explanation is reasonable for that
individual, not necessarily reasonable for anyone else who might be in
a similar situation.

It is because hypothesis formation is reasonable for the individual for
whom an event is surprising, that Peirce regards abduction as being
capable of explanation, at least psychologically, and thus being part
of scientific methodology.

The ways in which students indicate that an observation is surprising
obviously varies. In some instances the statement itself indicates
the element of surprise:

"Massive increase in the plankton" (FQ)

"Oh, no fish. Good God" (FQ)

In other instances the students make an observation statement, but then
say what they had expected to see:

"The fish numbers decrease more rapidly than the plankton. Would
expect the plankton to decrease more rapidly than the fish because
the fish are in large numbers." (NL)

"...the herbivores increase to more than the plankton which you
wouldn't expect." (NL)

For learning to take place this surprising data should lead to the
formation of new concepts in the form of hypotheses.

Peirce defines "making a hypothesis" as:

"Hypothesis is where we find some surprising fact which would
be explained by supposing that it was a case of a certain
rule, and thereupon adopt that supposition."

(Peirce, 2.623)
Many philosophers hold the view that the process of creating a hypothesis is one of a flash of insight, and thus one which cannot be explained by logic. Peirce, although believing that this process is one of a flash of insight, believes that it is a reasoned insight:

"You cannot say that it happened by chance, because the possible theories...exceed a trillion...and therefore the chances are too overwhelming against the single true theory...ever having come into any man's head."

(PEIRCE, 5.591)

However, the adoption of a suitable hypothesis following a "surprising" event includes not only the choice of a "reasonable" one, but also what seems to be the "best" one terms of "economy":

"Best hypothesis, in the sense of most recommending itself to the inquirer [my emphasis], is the one which can be most readily refuted if it is false."

(PEIRCE, 1.120)

and plausibility:

"An hypothesis is adopted for some reason, good or bad, and that reason is being regarded as lending the hypothesis some plausibility."

(PEIRCE, 2.511 n.1)

As in inductive theories, the hypothesis adopted should explain the observed facts and lead to conclusions which are capable of verification.

Occasionally the students will provide a reason, a "backup", for a hypothesis they choose to adopt to explain a surprising event. For example:

"There seems to be a new type of phytoplankton which probably has gained resistance to the pollution because it is reproducing very quickly. Changes in the system occur very quickly. Others would have been annihilated from the environment."

(DW)

Comment 1 indicates the surprising event "the rapid reproduction of the phytoplankton; comment 2 is the hypothesis put forward to explain this event; and comment 3 the reason provided for putting forward the
The following quotation is by a student using PONDGAME, the hypothesis is one which is intended to allow the person to make a profit from the fish farm by maintaining the number of fish in the farm:

"It just gets worse there in year 2. Should they go up? So you need lots of plankton, fewer herbivores and fewer fish. They are all dying of starvation the other fish."

In comment 1 the number of fish caught (not obvious from this quotation) is surprisingly low. Comment 2 is a hypothesis as to how this problem can be overcome, and comment 3 the reason why the hypothesis was put forward.

Peirce's theory predicts that a person adopts the "best" hypothesis of several that are the result of the reasoned intuitive process. There are a number of examples of students using the POND programs putting forward several hypotheses to explain an event. The most basic of these are those where several hypotheses are put forward without a choice being made, that is,

\[ S \rightarrow H_1 \rightarrow H_2 \]

as in the following two examples:

"I can't think why it kills the fish - besides being a poison in the water and a lack of herbivores, either poisoned or starved."

"The number of herbivores is decreasing and the number of fish. I don't know whether the fish are responsible for the herbivore decrease or the herbivores responsible for the fish decrease."

In both of these examples, the surprising fact is shown in comment 1, hypothesis 1 is shown by comment 2, and hypothesis 2 is shown by comment 3.
Occasionally the choice of the most plausible hypothesis can be observed as in the following series of quotations from a student who has polluted the pond and is surprised to see the fish decline in numbers (comment 1):

"The fish went down badly. Do they say what the pollution is? It must be something with ions in it! It must be a factory. Fish are always affected by poisons. The fish died, so have the herbivores. It must have been too much for the herbivores... The herbivores picked up again after half a year had gone... The fish could be dying for they have no herbivores to eat, but they probably died from the pollution."

The original hypothesis, to explain the decline in fish numbers was that of pollution (an obvious choice since this mode of the program was concerned with pollution) by ions. Later, however, NP noticed that both the fish and the herbivores had died (comment 3). This led to the hypothesis (comment 4) that the herbivores had been responsible for the fish decline, but the student almost immediately chose the best hypothesis (comment 5), that of pollution being the cause. Here the context within which the simulation was being used probably played an important part in determining what the "best" hypothesis was.

In the next example, the choice of hypotheses is concerned with the feeding habits of the fish population:

"As the fish increase the herbivores decrease (implies fish eat herbivores)... now seem to be feeding more on the plankton... Taking time for the fish and herbivores to increase. As they do, the plankton decrease. As the fish overtake the herbivores, the herbivores decrease, the plankton increase then. Therefore, the fish prefer feeding on the herbivores."

(MB)
Comment 1 was a surprising event, one which led to the hypothesis (implicit in what MB said) that the fish fed on the herbivores. Comment 2 showed an alternative feeding habit, that of feeding on phytoplankton. The choice of hypotheses was more or less resolved by a series of observations (comment 3) in favour of the fish feeding on the herbivores (comment 4).

An important part of scientific methodology, and understanding in general, is the verification of a hypothesis that has been recently adopted. This is shown by students using CAL programs, for example:

"As the number of phytoplankton increases, so does the number of herbivores. The phytoplankton are proportional to the herbivores. When the phytoplankton go down, so do the herbivores.

(PS)

In this quotation, the surprising fact (1) results in the formation of a hypothesis (2) which is then confirmed by another observation (3) in which the populations behave in the opposite way to that which was originally seen but which still confirms the verity of the original hypothesis.

In some instances, however, an observation may require the slight modification of the original hypothesis:

"The number of fish have not really picked up again. The total balance of fish is considerably lower due to fishing. The fishing is taking its toll on the population of fish which is decreasing. They cannot reproduce fast enough to replace those that have been caught.

(DW)

The series of events in this episode consists of a surprising event (1), followed by the hypothesis (2) that the fishing is "taking its toll of the population of fish". The observation that the fish are seen to be further decreasing (3) seems to require a slight shift in
explanation (4) where the fish are said not to be reproducing fast enough to replace those caught by the fishermen.

If the observations do not support the hypothesis, they will themselves be "surprising facts" and can result in the formation of a new and different hypothesis from the original:

"I thought there would be enough (fish)* there to improve it. But there isn't*(in March)* ... Do the fish eat plankton directly? I'm beginning to wonder...Try this one (INPUTs zero herbivores)*...I've got a lot of dead fish*...Fish eat herbivores* ."

(CH)

* my additions

Here, the series of events are more complex, becoming more of the process which is normally recognised as being "scientific". Following the surprising event (1), the student tentatively holds the hypothesis that the fish eat plankton (2). If an experiment is to be set up to verify or refute this hypothesis, the obvious one is to remove plankton from the pond. CH, however, performs an alternative experiment, that of removing the only other possible prey for the fish, the herbivores. When the fish die off (3) it forces a change in hypothesis (4). Implicit in this process is that CH must have deduced that if the fish eat herbivores they will die if no herbivores are present in the pond, and hence the INPUT of zero herbivores. This process of deduction was probably followed by a comparison of the prediction (the consequences of the INPUT action) and the observed events, which according to Peirce is induction. Since the predicted and observed events are seen to be the same, the hypothesis that 'fish eat herbivores' is confirmed. The process which CH probably carried out can thus be represented:

\[ S \rightarrow H_1 \rightarrow (H_2 \rightarrow D \rightarrow I) \rightarrow O \rightarrow H_2 \]

covered process
One can presume, therefore, that since the pattern of events that sometimes takes place during program runs conforms, at least in some instances, to what can be regarded as a scientific pattern of events, CAL programs can be said to promote scientific forms of activity similar to those described by Peirce.

Rosalind Driver (1983) has described the role of conceptual frameworks in how children explain scientific events. Her explanations of the process used by the children she studied have much in common with those described here.

In her book "The Pupil as Scientist?", Driver (ibid) provides a number of extracts of transcripts of children carrying out various experiments. One of these extracts concerns Richard and Carl who are studying friction between different surfaces:
Richard: We pulled it on the wood floor, a notebook, a bristly rug, a soft board and a tile floor.

Carl: Let's put it on the glass.

[The boys repeat their measurement on a large, glass-covered table]

Carl: 200 grammes! It's smooth, I thought it would be less.

[Carl continues pulling the block along the glass to the edge]

Carl: 175 grammes.

Richard: Where?

Carl: Seems odd. When you put it on the glass, as soon as you get near the edge, it takes less force to pull it, while you pull it in the middle it's pretty even. At the end it jumps down. $S_1$

Richard: Maybe we are not pulling it evenly. $H_1$

[Richard attempts to control this factor by using a battery-driven vehicle to pull at what he assumes to be a constant speed $D_1 I_1$]

Carl: Did it change? [referring to the spring balance reading]
Richard: Yes, but it got considerably lower. I think that may be inertia though. ^2

[To test out this idea he turns the tractor round, starting it off from the edge of the table ^2 I^2]

Richard: When it goes this way, force decreases. The other way it increases. 0^1

Carl: Maybe it's not level. ^3 Force would lessen going down, as gravity is helping you ^3

Richard: It looks level, though.

The boys then measure the level using a spirit level ^3 and find that the table does slope down at the edges 0^2

This sequence of events can be represented according to Peirce's notion of scientific methodology thus:

\[ S_1 \rightarrow H_1 \rightarrow D_1 \rightarrow I_1 \rightarrow S_2 \rightarrow H_2 \rightarrow D_2 \rightarrow I_2 \rightarrow O_1 \rightarrow H_3 \rightarrow D_3 \rightarrow I_3 \rightarrow O_2 \]
Driver (ibid., pages 62-3) says of these notable events in this learning episode:

$S_1$: "This observation by Carl obviously surprises both of the boys, as they had expected a constant reading on the balance".

$H_1$: "Implicit in this statement is the thought that the friction will depend on the speed at which the block is pulled."

$D_1$: "Richard attempts to control this factor by using a battery-driven vehicle to pull the block at what he assumes to be a controlled speed."

$H_2$: "Having controlled one possible variable, Richard now raises another hypothesis, that the change in the reading is due to inertia".

$D_2$: "(Later he explained that his idea here was that it takes more effort to get something going than to keep it going, and this might have been the cause of the fall in the spring balance reading)"

$I_2$: "To test out this idea he turns the tractor round, starting it off from the edge of the table".

$H_3$: "Having rejected the inertia hypothesis, Carl then suggests a further idea: that the change in reading is due to a sloping surface. Richard is dubious because the table appears level."
D\(_3\): This is not explained by Driver, but Carl indicated the
deductive thought processes by saying that "force would
lessen going down, as gravity is helping you."

I\(_3\)/O\(_2\): "The issue is finally resolved when the boys use a spirit
level and find the table does, in fact, slope down at the
edges... The boys have interpreted what was originally a
surprising observation in terms of an explanation they
accept: that of the incline."

The three hypotheses produced by these boys were reasonable hypotheses.
The first hypothesis (H\(_1\)) to be tested was probably selected for a
reason of economy. It is obvious to those performing and taking an
active part in an experiment that they may be at fault if the expected
results are not obtained. Causality is often related to a close
event, in this case it was an event (pulling) which was close in time
to the observation that less force is required near the edge of the
table. To choose any other hypothesis would mean that they were
overlooking an obvious cause of the surprising data.

Driver explained the process being used by Richard and Carl in this
learning episode as hypothetico-deductive thought. Their deductions,
although not indicated by Driver, are either implicit in their actions
(for example, D\(_1\) and D\(_2\)) or in their statements (for example, D\(_3\)).

The inductive process, as defined by Peirce, follows the creation of
the three hypotheses by Richard and Carl. In the first two cases the
inductive processes resulted in the refutation of the hypothesis, but
in the final case, in its acceptance as an explanation.
Although the hypothetico-deductive process is not unique to Peirce's notion of scientific method, he is noted for his emphasis on the creation of a reasonable hypothesis as a result of recognising a surprising event. "Reasonable" hypotheses are created by intuitive reasoning. It is thus possible to refer to these as "reasoned" hypotheses.

Driver recognises the importance of surprising events for the scientific process:

"...if it had not been for the original surprise in the uneven spring balance reading arising from an expectation that it should be constant, there would have been no investigation in the first place." (page 64)

For Driver, therefore, as for Peirce, the scientific process begins with the perception of a surprising event.

The creation of a hypothesis has been explained in terms of the conceptual frameworks possessed by the children. The statement, therefore by Popper (1960) and Copi (1953) that the creation of a hypothesis is not capable of logical explanation would thus seem to have been refuted.

Occasionally, my studies have shown that a surprising event has encouraged the creation of several, competing hypotheses. It is not evident from Driver's studies (1983) whether she detected a similar creation of competing hypotheses.

It is probable however that children and young adults either use successive scanning or partist strategies, or both, for concept selection and acquisition.
Scientific methodology is a means by which "nature", the "real-world", can be understood. Students who use a scientific approach to discover the various concepts "contained within" a simulation model appear to be exhibiting what has been described as a "deep approach" to the learning material (Marton, 1976; Entwistle, 1981). Since the learning approach a student adopts when faced with subject material is recognised as of importance in determining the outcome of a learning experience I attempted to classify the approach adopted by the students when using the POND programs using Marton's classification of deep active, deep passive, surface active and surface passive.

Although previous attempts at describing the approach adopted by students were concerned with that adopted whilst reading text in books etc., it seemed that it was equally applicable to the use of a CAL program. The approach adopted by a student can usually be found in their reply to the question posed in the post-run interview "What do you think are the main points of the program?". However, to fully ensure that their approach was correctly classified, evidence was obtained from the entire post-run interview and the observation protocols. The four types of approach are defined in the following manner:

Deep approach: is where the student's aim is to understand the content of the material, to be able to draw general conclusions and to think over the logic of the argument.

A deep active approach is where the content of the material is related to previous knowledge, where the evidence is related to the conclusions drawn, for example:
"I saw that the normal life, the natural life of a pond does not vary much between the years, but the effects that fishing has on it can be quite dramatic, and can change the balance of life a lot. Also pollution has a very major effect initially, but the balance of life returns, although the ecosystem isn't so complex losing fish unless reintroduced by man."

(DW:main points)

"To see how you were able to compare the statistics...the idea of constant populations, the idea of settling adaptations to...this was symbiotic...They all seemed extremely adaptable, if the conditions were right they could carry on, but as soon as the conditions changed they all went haywire."

(JH2:main points)

A deep passive approach is taken to be where the evidence is not related to any conclusions drawn, for example:

"I was thinking 'what if they had a lot of fish and not so many herbivores and phytoplankton?'...I was expecting if there wasn't a lot of food around the fish they won't survive."

(TS:main points)

"How to keep the pond stable with fish, plankton and herbivores."

(ST:main points)

Surface approach: is where the student's aim is towards the material itself and not to the underlying themes. "The student is not concerned with relating the material to reality.

A surface active approach is taken to be where the student tries to memorise what is happening, describes events without integrating them into a general argument. For example:

"Trying to make you understand a bit more about them...see how...herbivores, fish and phytoplankton adversely affect each other."

(NL:main points)

"It was trying to teach me that fish don't feed on herbivores...that the number of fish depends on the fishing rate, fish feed on plankton, pollution kills them all off...they all seem interrelated."

(DH:main points)
A surface passive approach is where the student doesn't really bother, loses interest and only mentions isolated points.

<table>
<thead>
<tr>
<th>Program</th>
<th>Surface</th>
<th>Deep</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>passive</td>
<td>active</td>
</tr>
<tr>
<td>POND-2</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>PONDQU</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>PONDGAME</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>POND2HELP</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1</td>
<td>15</td>
</tr>
</tbody>
</table>

Figure 10.3 Number of students using the POND programs in each of Marton's categories of learning approach.

Figure 10.3 shows that the students in these studies who used the POND programs were approximately equally divided into those who adopted a surface approach and those who adopted a deep approach. It is not surprising to find that the majority were surface active or deep active since the very nature of CAL programs demands an active student-CAL interaction. Since most of the students fall into the "active" rather than "passive" categories, I decided to merely look at what a surface and a deep approach meant for those using simulation programs.
<table>
<thead>
<tr>
<th>Type of concept formation</th>
<th>Mean number of concepts formed (proportion - as a percentage)</th>
<th>Level of Significance of Difference Between the Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface Approach</td>
<td>Deep Approach</td>
</tr>
<tr>
<td>A</td>
<td>0.93 (18.1%)</td>
<td>2.21 (21.9%)</td>
</tr>
<tr>
<td>B</td>
<td>1.33 (15.2%)</td>
<td>1.53 (16.2%)</td>
</tr>
<tr>
<td>C</td>
<td>2.40 (38.8%)</td>
<td>4.37 (39.5%)</td>
</tr>
<tr>
<td>D</td>
<td>1.93 (27.8%)</td>
<td>2.16 (21.4%)</td>
</tr>
<tr>
<td>all forms</td>
<td>6.60</td>
<td>10.26</td>
</tr>
</tbody>
</table>

Figure 10.4 A Comparison of Surface and Deep Approaches to the Use of the POND Programs with Respect to the Types of Concept Formation Demonstrated

Although those students who adopted a surface approach demonstrated the formation of a significantly lower number of concepts within each of my four categories (A - D) than those who adopted a deep approach (figure 10.4), the proportions of each of the four types of concept formation were similar for each level of approach (figure 10.4). Thus, besides the demonstration of a difference in the number of concepts formed, one must ask the question whether there are any other factors concerned with a surface/deep approach adopted by the students when using a CAL simulation.
### Surface Approach vs. Deep Approach

<table>
<thead>
<tr>
<th></th>
<th>Surface Approach</th>
<th>Deep Approach</th>
<th>Student's t-score</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>16</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. observations</td>
<td>30.2</td>
<td>41.4</td>
<td>1.194</td>
<td>-</td>
</tr>
<tr>
<td>No. surprising observations</td>
<td>3.6</td>
<td>5.9</td>
<td>2.306</td>
<td>95%</td>
</tr>
<tr>
<td>No. hypotheses formed</td>
<td>2.0</td>
<td>3.0</td>
<td>1.533</td>
<td>-</td>
</tr>
<tr>
<td>Hypothesis/surpr.obs. ratio</td>
<td>0.45</td>
<td>0.56</td>
<td>0.962</td>
<td>-</td>
</tr>
<tr>
<td>No. preconcepts</td>
<td>1.4</td>
<td>2.8</td>
<td>2.963</td>
<td>99%</td>
</tr>
<tr>
<td>related to food pyramid concept</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. concepts</td>
<td>7.9</td>
<td>10.8</td>
<td>1.172</td>
<td>-</td>
</tr>
<tr>
<td>related to food pyramid concept following program</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Surface Approach</th>
<th>Deep Approach</th>
<th>Student's t-score</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>15</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. experimental activities</td>
<td>4.3</td>
<td>4.4</td>
<td>0.090</td>
<td>-</td>
</tr>
<tr>
<td>No. strategic actions</td>
<td>7.5</td>
<td>7.5</td>
<td>0.030</td>
<td>-</td>
</tr>
<tr>
<td>No. valid + invalid concepts</td>
<td>7.9</td>
<td>10.8</td>
<td>1.172</td>
<td>-</td>
</tr>
</tbody>
</table>

(excl. PONDGAME)*

<table>
<thead>
<tr>
<th></th>
<th>Surface Approach</th>
<th>Deep Approach</th>
<th>Student's t-score</th>
<th>Level of Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>10</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. experimental activities</td>
<td>1.3</td>
<td>3.1</td>
<td>1.974</td>
<td>90%</td>
</tr>
<tr>
<td>No. strategic actions</td>
<td>2.9</td>
<td>6.1</td>
<td>2.168</td>
<td>95%</td>
</tr>
<tr>
<td>No. valid + invalid concepts</td>
<td>5.1</td>
<td>10.8</td>
<td>2.110</td>
<td>95%</td>
</tr>
</tbody>
</table>

* Because PONDGAME by its very nature encourages a greater number of experimental and strategic activities than the other POND programs, it was felt that a more satisfactory comparison would be obtained if the students who used PONDGAME were excluded from this part of the statistical analysis.

**Figure 10.5** A comparison of the activities of surface and deep approaches of students using the POND programs.
Students using CAL simulations behave differently in that some INPUT a large number of sets of data, make a large number of observation statements, conceptual statements etc. Figure 10.4 shows a comparison of students adopting a surface and a deep approach with regard to what I see as their possible major characteristics.

From figure 10.5 it seems that those students with a good initial knowledge of the concepts related to the main concept ("food pyramid") of the simulation will adopt a deeper approach to using the programs.

This students who adopt a deep approach when using these CAL programs appear to make significantly more surprising observations than those who adopt a surface approach.

This is probably because they have a better conceptual base from which to work. Those with a poor conceptual base will not be surprised, but initially accept what they see as the truth and build their conceptual structures accordingly.

Although there isn't a statistical difference between the mean number of hypotheses formed by students having the two approaches, those who adopt a deep approach demonstrate a statistically higher number of experimental and strategic activities and a higher number of concepts than those who have a surface approach. Not surprisingly, therefore, the adoption of a deep approach is one which is probably going to be more successful for the students, and thus should be encouraged by the program.
When a student uses a CAL program which simulates a particular part of
the real-world, that student may use a variety of "scientific" methods
(for example, by setting up and observing controlled experiments)
and/or "non-scientific" methods (for example, by merely pressing keys)
to attempt to discover and describe the nature and behaviour of that
simulation model. The student will make a number of observations of
the behaviour of the simulation model and might then formulate
reasonable hypotheses to explain those observations.

People appear to have an inborn, intrinsic desire to discover and form
relationships which attempt to make sense of the world in which they
live - in these studies, it is the simulation program that they are
using. Popper (1980) sees these relationships having an important
predictive role. He sees the formation of relationships as "an inborn
reaction or response to impending events".

It is important that program designers do not assume that an individual
will always come to realise the "true" relationship between the various
parameters of a simulation model. Also, they must not assume that
invalid conceptions will be followed by the formation of the valid
concepts. Conceptual exchange, as I will show, does not always occur
even if the observations made by a person appear to demand it.

On those occasions during a program run when the validity of a concept
is challenged, it is often said that there is cognitive or conceptual
conflict.
When there is conceptual conflict, there appears to be two main options, or pathways for that person. They can either exchange concepts, or they can retract from the conflict situation.

Popper (1980) says that if observations show a hypothesis to be wrong, then a person may create ad hoc definitions and hypotheses to support the initial hypothesis, or that person may even refuse to accept the falsifying evidence. Retraction from the conflict situation during the use of a CAL program can occur apparently in three ways for users of CAL programs. I will consider each of these four options in some detail:

10.3.1 **Option 1: Conceptual exchange**

The student can change the nature of the concept, or hypothesis, which has been previously used to explain observations. The new concept should explain all previous observations and the current observations. When a concept is challenged, the introduction of the new, more plausible, more fruitful concept occurs, but it appears to be a gradual introduction in many cases.

When introduced, a new concept sometimes appears as a second and alternative concept together with the existing concept. The student now has a choice of concepts, say concepts A and B. It may be that the most appropriate concept (concept A) is brought to the forefront in a particular context. This concept (A) may then recede into the background of the student's mind when another context is evident. In
this different context, the alternative concept (B) is dominant. Each concept, therefore, may be dominant in a particular kind of context and recessive in another. The process is somewhat analogous to that of a pan balance, each pan representing a particular conceptual belief. The observations made in a particular context will sway the balance one way or the other. When weighed down by these observations that concept can be said to be the dominant one. This sequence of events has similarities to the notion of "everyday, lay" and "science concepts".

This sequential emergence and regression of concepts during a program run, as different contexts and situations are encountered by the student, can be observed by comparing chronological episodes of a student's program run. Such cases tend to be complex, probably because of the very fact that there is a conflict in the individual's beliefs.

The following example of such a conflict situation is taken from DW's program run using POND-2 where he has INPUT to fish the pond. When the results are OUTPUT by the computer he said:

"The number seems to decrease with fishing\(^1\)...Let me see what effect it has on the phytoplankton. The number of phytoplankton seems to be less during the fishing season\(^2\). It does not seem to take effect until after about one month. The number of herbivores seems to decrease somewhat\(^3\), perhaps because the fish have gone..."

This quotation shows that DW appears to know that fishing causes a reduction in the size of the fish population (comment 1), and that this change in population size results in a decrease in number of the phytoplankton (comment 2) and herbivores (comment 3). DW then went on to explain why he thought the plankton and herbivore populations had
decreased as a result of a decrease of the fish population:

"...Fish excretory matter feeds the phytoplankton, therefore, the phytoplankton are decreased, and also the herbivores, and maybe the fish?"

With a decrease in the size of the fish population, the amount of fish excreta would also decrease. DW saw (comment 4) the plankton feeding on this excretory matter, and thus declining when the fish declined in numbers.

Comments 5 and 6 both appear, at least superficially, to say that he also believes the herbivores and the fish to feed on the fish excretory matter. In an interview, I tackled this student about this, and he confirmed that he saw the herbivores feeding on the plankton, and the fish feeding on the herbivores.

If the concept of plankton feeding on fish excretory matter were a valid concept, then the possible consequences of it and the concepts that "herbivores feed on plankton" and "fish feed on herbivores" can be shown to be illogical and thus invalid:

![Diagram showing the interconnections between fish, herbivores, plankton, and excretory matter.]

- FISH DECREASE
- HERBIVORES DECREASE
- PLANKTON DECREASE
- PLANKTON DECREASE
- HERBIVORES DECREASE
- FISH DECREASE
- fish feed on herbivores
- herbivores feed on plankton
- plankton feed on fish excretory matter
The only consequence of these conceptions is that all three populations would decrease to the point of extinction. There is no allowance for another factor to cause any one of the populations to increase.

In an interview with DW six months after his use of the program, I went through the OUTPUT data he had obtained during his program run. Interestingly, using the stimulated recall technique, he explained the same set of data in a similar way. He put forward the misconception of plankton feeding on the fish excretory matter to explain the decrease in size of plankton population.

The example I gave in section 9.3.2 showed how PS had misinterpreted the OUTPUT data. DW had behaved in a similar way in this episode, as the results he obtained show:

<table>
<thead>
<tr>
<th>YEAR 1</th>
<th>MONTH</th>
<th>PHYTO-PLANKTON (x 10^6)</th>
<th>HERBI-VORES (x 10^6)</th>
<th>FISH CAUGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAN</td>
<td>150</td>
<td>23</td>
<td>807</td>
<td>CLOSE</td>
</tr>
<tr>
<td>FEB</td>
<td>314</td>
<td>29</td>
<td>862</td>
<td>CLOSE</td>
</tr>
<tr>
<td>MARCH</td>
<td>317</td>
<td>58</td>
<td>666</td>
<td>CLOSE</td>
</tr>
<tr>
<td>APRIL</td>
<td>391</td>
<td>55</td>
<td>1333</td>
<td>139</td>
</tr>
<tr>
<td>MAY</td>
<td>271</td>
<td>68</td>
<td>3138</td>
<td>331</td>
</tr>
<tr>
<td>JUNE</td>
<td>354</td>
<td>49</td>
<td>1913</td>
<td>266</td>
</tr>
<tr>
<td>JULY</td>
<td>327</td>
<td>70</td>
<td>1425</td>
<td>184</td>
</tr>
<tr>
<td>AUG</td>
<td>292</td>
<td>58</td>
<td>1010</td>
<td>268</td>
</tr>
<tr>
<td>SEPT</td>
<td>230</td>
<td>60</td>
<td>844</td>
<td>96</td>
</tr>
<tr>
<td>OCT</td>
<td>152</td>
<td>55</td>
<td>667</td>
<td>CLOSE</td>
</tr>
<tr>
<td>NOV</td>
<td>137</td>
<td>40</td>
<td>598</td>
<td>CLOSE</td>
</tr>
<tr>
<td>DEC</td>
<td>125</td>
<td>35</td>
<td>509</td>
<td>CLOSE</td>
</tr>
</tbody>
</table>
Figure 10.6 shows that the fish and the plankton decreased during the fishing season as DW said (comments 1 and 2 respectively). The herbivores, however, did not decrease as he said (comment 3), instead they showed a slight increase.

DW went on to look at the next year's data. He once again observed a decrease in the size of the fish population, and he commented:

"In the second year, the effect of last year's fishing causes the balance of herbivores to increase during the close season... The herbivores are increasing because there are not so many fish around."

This is the conception that is valid, that herbivores increase because, presumably, the student believes that there is less predation on this population by the fish. DW continues:

"It has an effect on the phytoplankton... during the fishing season the number is decreasing faster than without fishing."
Comments 7 and 8 show a change in conceptual belief from that demonstrated by comments 5 and 4 respectively. Comment 5, for example, indicated that the herbivore numbers were related to the phytoplankton numbers. Comment 7 indicated that they were related to the number of fish. More markedly, comment 4 indicated that the plankton were believed to feed on fish excreta, and comment 8 implies that the herbivores are affecting the size of the phytoplankton population. But then he continues:

"Probably the amount of excretory matter being produced - benefiting the herbivores who are taking advantage of this."

It is hard to believe that this is a reasonable belief from the observations he had made. It implies that the herbivores are feeding directly on the excretory matter and not the phytoplankton. It almost appears as if the student is finding difficulty in believing that the increase in herbivores is a result of a reduced predation by the fish, and resorts to his recent, but past, conceptual belief as a means of explaining the data.

DW appears to maintain at least two concepts which he uses to explain the data. One concept, a misconception, which is most commonly provided in these episodes as the explanation of his observations. The second concept seems to be an emerging concept, and is more or less kept in the background. It only emerges in the way in which he relates certain of the observations.
Following his use of this mode of the program, DW goes on to pollute the pond, and demonstrated the valid concepts which one would expect to be made:

"...it probably kills the phytoplankton first of all - cutting out the light or changing the chemical balance in the water, and thus affecting the herbivore and fish numbers. Once the phytoplankton are dead, the others will die."

It is now evident that his understanding of the interrelationships between the trophic levels has moved towards the valid concepts since he has realised that the other organisms are dependent on the phytoplankton. When he held the misconception (concept 4) as his apparent major concept, the pond organisms were dependent on the fish (excreta). Hence the plankton are seen as being affected by the light or chemical balance in the water. Throughout the remainder of his program run, DW appeared to maintain valid conceptions of the interrelationship of the pond organisms.

An example of an immediate exchange of concepts is difficult to find. Students tend to change concepts gradually as I have demonstrated, but one such example occurred during SB's program run using POND2HELP when a valid concept was exchanged for a misconception.

During the early part of SB's program run, it was apparent that he believed, quite correctly, that the fish were proportional to the herbivores. During this run (after 30 minutes) he INPUT $50 \times 10^9$ phytoplankton, $25 \times 10^6$ herbivores and 1000 fish. On the OUTPUT of the data, he made the following comments:
"Looks as if the fish are keeping the herbivores down.\(^0\)
No...Herbivores seemed to have suffered a bit. Dropped almost to zero (* was zero). At that point the fish increased incredibly. Looks as if I have run out of herbivores."

(* my addition)

Although nothing consequently surprising seems to have happened here, he sees the fish and herbivore numbers as being related (comment 1), it transpired from the post-run interview that a significant conceptual change had taken place at this time:

I: Did you ever really sort out what the fish were feeding on in this program?
SB: Yes, I did. After I'd killed off all the herbivores, it was interesting to see the carnivores were still plodding along\(^2\). So they had obviously been feeding on the plankton\(^3\)
I: So you reckon they were actually feeding on the plankton?
SB: Directly.

The fact that SB had observed the fish surviving over a period of time longer than he had probably expected (comment 2), was sufficient for a conceptual change (comment 3).

10.3.2 Option 2: Retraction from a Conflict Situation by the Invalidation of Perceived Events, or the primacy of Pre-established Beliefs

If a conflict situation arises because certain perceived events are regarded according to an existing conceptual structure, then one way to retain that conceptual structure rather than reject it it is to say that the results are wrong. This is similar to Kelly's notion of hostility. In such a situation the observations made do not fit the theory held and thus these observations must be wrong! The concept can thus be maintained without any further apparent conflict. This
can lead to dialectical comments being made.

An example of such a dialectical statement is given below:

CP, using PONDQU, decided to fish the pond. He compared the data obtained during the first year he fished the pond with previously obtained data and observed:

"The herbivores stay the same, the phytoplankton stay the same. Surprising! It doesn't make sense the herbivores should increase."

He had already demonstrated that he believed:

1) that fishing reduces the fish population, and
2) that the herbivores are reduced by fish predation.

Both of these concepts would logically lead to the deduction that fishing should lead to an increase in herbivores (comment 3). He didn't see such an increase (comment 1), and said that the data didn't make sense (comment 2) thus implying that the data was wrong.

10.3.3 Option 3: Retraction from the Conflict Situation by repudiation (of Context or Hypothesis)

Rather than saying in a conflict situation, as in 10.3.2, that observations are incorrect, or appear to be incorrect, the student may say that the concept does not apply to this particular context, and that another rule must, therefore, apply. This is similar to Kelly's notion of extension of the range of convenience of a construct to contain a new element. This is shown diagrammatically in the following example:
By saying that the rule does not apply, and not producing a new concept to replace it for these months of the year (February to March), the student (PN) appears to have been able to retract himself from the conflict situation. When observing students using CAL programs in a conflict situation, there may be an explicit comment which says that a concept does not apply, or it may be implicit in other comments that are made.
10.3.4 Option 4: Retraction from the Conflict Situation by Ignoring It

An alternative to previous forms of retraction, and a more positive form, occurs when, instead of suggesting an alternative hypothesis, or saying that observations are incorrect, the student totally ignores the conflict and proceeds on to another part of the program, as in the following example:

The conflict situation is, of course, uncomfortable for the student, and one of the easiest ways of "resolving" it must be to ignore it and go on to another part of aspect of the program.
10.3.5 Comments

Pickering and Monts' (1982) experiments, which examined ways by which freshman students reconciled discordant data in a chemistry experiment, are interesting in that the specific strategies they describe their students using can be categorised in a similar way to the options I have described above. The strategies Pickering and Monts observed were specific in that they referred to the "major thrust of the student's argument rather than any pure 'intellectual style'". Osborne, Bell and Gilbert's (1983) description of alternative treatments of information by students also show similarities with these options I have described for students using a CAL program.

When an individual's beliefs are brought into a conflict situation by a particular experience, there appears to be only two major routes which he can take. He can either change the nature of his concept to account for both the new experience as well as all previous experiences which had been explained by the replaced concept; or, he must retract from the conflict situation by saying that there is an error in the data, or that the concept is irrelevant for that particular context, or by merely refusing (or lacking the motivation) to resolve the conflict.

CAL programs should be designed so as to provide situations where, if misconceptions exist, a state of cognitive conflict can be initiated without inhibiting the intrinsic desire of the program user to investigate the simulation model.
In these studies, a satisfactory method for initiating cognitive conflict appeared to be by the provision of cues, in the form of questions used in POND2HELP, which can provide alternative conceptions. Multi-choice questions, such as those used in PONDQU, which must be answered correctly before further use of the simulation model can be made, are unsatisfactory in that they often result in a marked decrease in experimental types of cognitive activity.
Chapter 11

A Global Discussion of Results and their Implications for Education and Further Research

11.1. Introduction

The main purpose of these studies was to observe and describe the effect of the structure of CAL programs on the learning activities of students. This aim has been successfully achieved, but in so doing a number of problems, usually in methodological design, have arisen. Many of these problems were tackled, but time has not always allowed a satisfactory answer to be developed.

These studies have also provided some insight into areas other than that of the design of CAL programs. They have implications, for example, for the teaching of science and curriculum development.
The title of this dissertation ("From Surprise to Cognition") was chosen because it represents not only the events that occurred as I came to understand the cognitive processes taking place in the minds of students participating in these studies, but it also explains my understanding of the cognitive processes taking place in minds of these students. Learning, at least in the context of CAL, appears to take place in an inductive direction (page 246). However, according to modern philosophy and theories of perception, observation, the basis for induction, is itself a theory-laden event. This belief has tended to attract philosophers towards deductive theories of scientific methodology and epistemology usually avoiding the inclusion of perception in the logical part of the process. However, the observation of students in a learning situation will illuminate the important role that perception has in initiating learning (page 330).

I have been surprised by the important role that perception, and especially the perception of surprising events, appears to play in the heuristic, pedagogic process. This surprising role of perception in pedagogy led me to search for an existing theory of abduction and thus to become cognisant of Peirce's Pragmatic Theory of Abduction (page 214), which includes surprising data and events as the starting point for scientific discovery. This theory also includes deductive and "inductive" stages in the scientific process. In this theory there appears to be a marrying of the various inductive and deductive theories of scientific discovery and concept formation.
The importance of surprising events and data in cognition is evident in the word "recognition". If one is familiar with something, then we say that we recognise it. Cognition, therefore, only takes place when one is not familiar with the data or event, in other words, the data or event is surprising.

Throughout this dissertation I have emphasised some of my findings. These findings not only indicated at the time the direction in which I should develop the method by which I could analyse conceptual learning, but they also emphasise matters concerning the design of CAL programs so that they might promote a desired range of cognitive activities. These important points are brought together and listed below in two digests.
Digest of Points Concerning the Development of a Suitable Method of Evaluation of Learning

1. CAL programs encourage a varying range of cognitive activities.
2. Individual students demonstrate a varying range of cognitive activities.
3. Concept maps provide a summative, complex and ambiguous representation of conceptual learning.
4. Conceptual learning is, to a large extent, individualistic in nature and thus the method of evaluation used should also be flexible.
5. The Interaction Model allows a detailed analysis of learning episodes.
6. The Interaction Model is flexible in that it can be used to describe the events involved with any learning episode (in the context of CAL).
7. The Interaction Model represents a similar sequence of events as described in Peirce's Theory of Abduction and Driver's description of learning in children.
Digest of Recommendations for the Design of CAL Simulation Programs

1. Program authors should be guided by a number of important factors when considering the form in which numerical data is to be presented by a CAL simulation program:
   a. the students for whom the program is designed,
   b. the purpose of the data - i.e. whether it is intended for numerical manipulation or as a means of communicating information,
   c. to have a choice of forms of presentation - individuals vary in their preferred style of data presentation, also the perceived goal of the program can influence the choice of style of presentation.

2. Since CAL programs appear not to enforce a hierarchical acquisition of concepts, programs should be designed so as to allow a flexible approach to conceptual learning.

3. Programs should be designed so as to provide cues which can act as alternative conceptions to those possessed by students, and can thus promote an investigation of the simulation model.

4. Programs should promote a full use of the simulation since there seems to be a direct relationship between the amount of OUTPUT data obtained and the formation of valid concepts.

5. A deep approach to learning should be encouraged since those who adopt this approach appear to demonstrate a larger number of "surprising" observations and investigative activities of the simulation model.
The discussions in this final chapter of my dissertation, will be divided into four areas:

(i) The evaluation of learning,

(ii) Some effects of program structure on learning,

(iii) CAL as a means of science education,

(iv) Implications of the research for curriculum development.

11.2 The Evaluation of Learning

Published work (for example, Laurillard, 1978a; Kemmis, 1977a and 1977b; MacDonald, 1977) on the learning activities of students using CAL programs have been mainly concerned with the qualitative nature of the Student-CAL Interaction, often in an attempt to provide a "helpful" package. Laurillard (1981) said of the methodology commonly used in protocol analysis:

"By relating the students' conversations to the concurrent stage of the package, it is sometimes possible to determine the features of a package that particularly help or hinder the students."

These studies have not been directly concerned with the improvement of a particular package, but have attempted to determine some of the features of a simulation program that will encourage or discourage certain learning activities. They have been concerned, therefore, with examining the dynamic process of learning.
Learning is a dynamic process. A body of knowledge grows with time and it also changes its nature with time in that it may become related to previously unrelated bodies of knowledge. Kemis (1977b) describes a "data-matrix" model which recognises this dynamic nature of the learning process. The analysis of the data matrix is one of pattern recognition, and "the coherences between the action and discourse will begin to reveal cognitive structures." [page 285].

In my studies, a necessity became apparent for a method of protocol analysis that showed not only the dynamic nature of the learning process but also the effect of such factors such as previously acquired knowledge (page 196).

The pilot studies used a qualitative form of analysis which showed the differences between various learning milieu (CAL programs, tutorials, laboratory practicals) in terms of the kind and frequency of cognitive activity exhibited by the students. This form of analysis shows the final effect of program structure on learning. It shows that program structure does affect learning. It shows that individual students exhibit marked difference in learning behaviour. But it does not show how or why these effects occur (page 127).

The methods subsequently developed evolved from "concept maps" to show the developing relationships between various concepts, to the "Interaction Model" which is used here as the main method of protocol analysis.
The use of concept maps shows the individual nature of conceptual structures as well as the similarities in conceptual development. Initially the concept maps represented a summary of the concepts acquired during a program run and the ways in which they had been shown to be interrelated. These initial concept maps were designed from my specific ideas as to the concepts that a student should acquire by using the POND programs. In a number of ways, these expectations limited the kind of results that could be obtained.

By limiting my perception of the result of learning, for example, to those valid concepts that I expected to be acquired meant that a significant part of the learning process, alternative and invalid conceptions, are omitted. The inclusion of all concepts formed, the observations leading to these concepts and the INPUT actions producing OUTPUT data from which observations can be made resulted in concept maps having a more dynamic nature. However, the degree of complexity often shown by these maps leads to difficulties in their interpretation (page 254). More seriously, the structure of these maps can lead to artificial relationships being formed. This ambiguity, the result of combining a series of learning episodes, has been observed elsewhere (Gravina, 1981).

The Interaction Model was developed as a result of the realisation that the common factor between episodes of a program run was a pattern of events consisting of:

ACTION ـــــ► OBSERVATION ـــــ► CONCEPTION
This is similar to Kemmis' notion of learning events represented by the phrase "action and discourse" in the data matrix model (Kemmis, 1977b [page 284]). In the Interaction Model (page 282) I have divided "discourse" into two separate types of activity "observation" and "conception". I also recognise in the design of the Interaction Model that various intrinsic and extrinsic factors can influence learning.

The Interaction Model is used to produce chronological, episodic representations of the learning processes demonstrated by students using a CAL program. Research of this kind is, of course, extremely dependent on individual students revealing all that they see and think, an extremely unlikely occurrence! Much work in the past on learning using computers has depended on at least two people working together at a terminal. Laurillard (1981), for example, has said of two students working together in this way:

"One major advantage of...working together...is that they talk together about the difficulties they have, and this can provide extremely valuable information."

However, I was interested in describing how CAL programs promote learning, and this, I believe, necessitates studying individuals rather than small groups of students.
It should be recognised that when evaluating any form of learning that the analysis can only be carried out using a limited amount of evidence. Stimulated recall techniques, interviewing very soon after the learning experience and asking the student to comment on the analysis can all aid the development of accurate conclusions. I only used the first two of these aids in all of the case-studies to obtain as much evidence in addition to that obtained during the program run.

The final analysis of protocols using the Interaction Model was, in many cases, carried out after the students had left the College. This meant that to discuss my interpretation, that is, the diagrammatic representation, of a student's program run was usually out of the question.

Once each student's program run has been analysed in detail and illustrated diagrammatically it is possible to return to the ideas used by previous workers in their qualitative protocol analysis. In my pilot studies I produced a hierarchical typology of cognitive activities which I believed to be relevant for protocol analysis. I have been able to illustrate what I believe each of these cognitive activities would consist of in terms of the Interaction Model (pages 288-306). Each cognitive activity entailing a typical arrangement of events representing this particular learning experience.

The series of diagrams representing a student's program run are further analysed to show a quantitative estimation ("estimation" because I cannot ensure that all observations and conceptions made by an individual are divulged during the program run or the post-run interview) of the activities demonstrated by each person. With a
quantitative estimation it is now possible to correlate certain cognitive activities and see how these correlations are affected by program structure (pages 313-337).

Statistics have not been used in these studies as a strict means of proof or otherwise. I have used statistics mainly as an indication of probability. The results of statistical tests have been usually used to substantiate my analysis of the available data, or as a means of indicating to me an area where I should look to see whether a relationship between certain cognitive activities, for example, appear to exist and whether I can attach meaning to that apparent relationship.

It is thus possible to analyse protocols both qualitatively and quantitatively, the results of which can be used in different ways. Qualitative results can be used, for example, to identify an ineffective program or part of a program. However, to identify how program structure can affect learning requires a dynamic, and, at least in part, a quantitative approach. These studies have moved towards this approach from the qualitative one I adopted early in my studies based on the work of others.
11.3 Some Effects of Program Structure on Learning

From my early pilot studies it was evident that:

(i) different CAL programs encourage a different range and proportion of cognitive activities, and

(ii) individuals show different types of cognitive activity.

Laurillard (1978a) has said that little is known of the effect of program structure has on learning. Of the effect of program structure on learning, Kemmis (1977b) has said:

"The analysis of student-CAL interaction in terms of f-structures [functional structures]* and d-structures [dynamic structures]* suggests that learning milieu always exert an influence on what is learned (by affecting how it is learned)" (page 406)

([ ]* my addition)

Much of the effect of program structure can be ascertained by identifying the cognitive activities demonstrated by students during their use of CAL programs, by determining whether any correlations appear to exist between these activities, and finally by determining the identity of the concepts acquired and the order in which they are acquired.

For these studies three POND programs (PONDQU, PONDGAME and POND2HELP) were written based on a program (POND-2) obtained from a commercial publisher but modified by myself so as to give a suitable VDU presentation and a hardcopy printout of the data. All four POND programs are thus based on the same simulation model, but vary, for example, in the way additional and supportive information is supplied to the program user (as in PONDQU and POND2HELP) or vary in the way the simulation is presented (POND-2 being a "normal" investigative CAL
program and PONDGAME a game version relying on the person's instinct to win as a means of encouraging the development of the appropriate conceptual structure). By designing and writing a "suite" of similar programs based on a commercial program I thought that I would be better placed to compare the effect of program structure than by using a number of different commercial programs having different structures but also probably also using different simulation models.

In designing and writing my own programs I was compelled to devote some considerable time not only in those activities, but also to ensure that the modified programs ran satisfactorily. However, because of the demands of time and with an insufficient number of available students, the kind of program testing that might be carried out for a normal CAL program had to be omitted. In retrospect, now that the programs have been used, minor modifications should have been made. I feel, however, that in not testing and not making these modifications I have not affected the nature of these studies in any serious way.

Much of the effect of program structure on learning was illustrated by the scenarios (pages 331-337) of how various types of student might behave when using a POND program and on the forms of concept learning encouraged by each of the programs (see figure 11.1).
Figure 11.1 The proportion of forms of concept learning activities encouraged by the POND programs
In general, students who use any CAL program must be familiar with the form of data presentation whether it be in the form of diagrams, tables, graphs etc. Without this initial ability to translate the data presented to them, great difficulty will be encountered in understanding the simulation model. Such difficulty was often initially encountered (page 181) by those who used the low-resolution graphs in POND-2, PONDQU and PONDGAME. However, the graphs can also only be correctly interpreted if the students have the ability to do so. A considerable number of the students using the POND programs failed to recognise the scaling factors for the y-axes of the graphs and even on the tables! It is here that the sensible use of colour to highlight specific important points could be extremely useful.

The preconceptions that a student has of the simulation model are important in affecting what is learnt. Surprisingly, having previously acquired a good understanding of the concepts the CAL program is designed to "teach", can inhibit experimentation with the model (page 333). This brings into question the often stated purpose of CAL simulations "to enrich a student's understanding of a topic taught in another learning milieu".
In these studies the students were working alone and received no encouragement to use the programs. All they were instructed to do was to use the program until they felt that they had learnt all that they could from it. There were no other stated objectives as might be provided, for example, by a teacher who expects the program to be used for a particular purpose. On the other hand, CAL programs such as these POND programs might be used for independent learning where it is necessary for it to stimulate its user, to maintain a suitable level of intrinsic motivation in that person so that the simulation model is satisfactorily investigated. The more observations made, the more the likely it is that the student will come to understand the model.

PONDGAME proved to be extremely successful at maintaining interest in using the program even though the student had a feeling of frustration because they could not make a continued profit. A modification of PONDGAME might allow the fish farm to make a continued profit, that is, allow the pond to maintain an equilibrium even though fish are removed from it.

PONDGAME distracted the students from the objective I gave to them for using it, that is to learn about pond ecology. They preferred to try to make a profit! Because they have this overriding aim to make a profit, they refuse to pollute their pond especially with high levels of pollutant. A redesigned POND game might pollute the pond at any of the three possible levels at randomly determined times. This would remove the responsibility to study the effect of pollution on the pond ecosystem from the student to the program designer.
Those students who have little or no knowledge of the concepts the CAL programs are designed to "teach" appear to benefit the most from using them, probably because they experiment with the simulation, test hypotheses etc. This means that they make observations of the behaviour of the model and come to understand many of the relationships that exist.

In attempting to provide assistance to students to understand a simulation model, care must be taken as to how it is performed otherwise the very act of providing assistance will inhibit learning (page 335).

This inhibition of learning is shown very well by those students who used PONDQU. Compared to the other POND programs, PONDQU encourages relatively few concepts. In requiring answers to be given to questions concerning the food pyramid concept, and thus "ensuring" that certain, relevant concepts are acquired before progression to other parts of the program, students appear to feel that they understand the program. "Spoonfeeding" concepts appears, however, to inhibit investigation and experimentation. To be passively "indoctrinated" does not successfully lead to meaningful learning.
POND2HELP, on the other hand, employed an alternative strategy. Questions were answered by the users of the program, but the program user was given no indication whether their answers were right or wrong. In addition to determining the nature of the help that should be provided to the program user, when so requested, these questions appear to provide alternative conceptions and hypotheses to the person. These alternative conceptions and hypotheses appear in some cases to be investigated by the students, and can thus promote an understanding of the model (pages 334-335).

Students participating in these studies infrequently used the help available in POND2HELP. However, those who use it can find that it can encourage them to look differently at the available data (have an alternative "epistemic tube"). In this way, there may be a change in conceptual belief.

The argument that meaningful learning can only occur if concepts are presented according to a particular hierarchy appears, form these studies, to be incorrect. There is evidence that it is necessary to ensure the early, initial acquisition of certain concepts essential for interpreting a simulation. However, thereafter, it appears that students will acquire concepts in a variety of orders, relating them to one another in their own personal manner.
Previous workers in this field such as Shavelson (1972), Preece (1976), Baird and White (1982) and West, Fensham and Garrard (1982) have been able to produce cognitive maps which have seemingly shown the hierarchical development of various areas of knowledge. It is extremely difficult to produce any cognitive map which accurately illustrates the structure of an individual's conceptual knowledge. West, Fensham and Garrard recognise that the method whereby an individual, for example, rates the degree of relationship between provided statements can actually lead to a learning situation and thus the creation of a somewhat different conceptual structure from that which would have otherwise existed.

Shavelson (1972) and R.T. White (1974) have reported that the provision of highly structured instructional material results in students acquiring a conceptual structure similar to that of the learning material. I found it very difficult to find any marked effect on an individual's conceptual structure resulting from the effect of presenting concepts according to a particular hierarchy (page 272).

Undoubtedly, the hierarchical presentation of learning material does aid learning. By showing the relationships that exist between certain theoretical ideas or physical laws, for example, can encourage a student to develop their ideas and relationships between them in a similar way. However, regard must be taken of those unpredicted ideas that are acquired which an expert would not accept as being valid.
The use of the Interaction Model has been restricted in these studies to analysing the cognitive events accompanying the use of a small group of somewhat similar simulation programs. Tutorial programs are usually based on a didactic approach to learning in that they attempt to convey a certain body of knowledge. An investigation of tutorial programs and of the many other forms of simulation program using the Interaction Model to analyse the cognitive events will probably result in a more detailed understanding of how CAL and CAI work. Thus, we may learning how they might be designed so as to allow a flexible approach to learning, an approach which also includes the recognition of the importance of alternative conceptions in the development of individual conceptual structures. Present attempts in designing programs which make use of "expert-systems", although a development in the right direction, do not allow, at present, the degree of flexibility that I believe should be built into the programs.

The presentation of highly structured learning material (as, for example with PONDQU) need not result in "meaningful learning", that is, the assimilation of a body of knowledge which is related to previously acquired knowledge. A body of knowledge may be acquired through such learning material, the person may have learnt by rote the relationships that are provided between the various concepts within that body of knowledge. However, it is only when those relationships can be personally generated will that knowledge have personal meaning. Thus, meaningful learning may be facilitated by the presentation of less highly structured learning material as, for example, with PONDGAME.
The purpose of science teaching can be regarded as the furnishing of students with the knowledge they require for professional practice (Kuhn, 1970). "Scientific Knowledge" for professional practice should be regarded as being composed of three parts:

a) conceptual knowledge - the cumulative knowledge of the scientific community regarded as being "true" by that community;

b) the laboratory skills necessary to practise science;

c) knowledge of how scientific discoveries can and should be made.

For most science students, their academic studies consist of acquiring conceptual knowledge and the appropriate technical skills. Little emphasis is placed on experimental design, problem-solving and the overall process of science as practiced by the professional community.

CAL simulation programs are said to be useful for enriching a student's understanding of a particular topic area. They can be used as a means of encouraging experimentation and problem-solving in a situation where it is not necessary to practise practical skills. Two important questions must therefore be posed:

i) Do CAL simulations promote learning?

ii) Do CAL simulations promote scientific activity?
The first of these questions has been answered and reported many times before by other workers. In these studies, I found that there was an increase in knowledge demonstrated by many of the students about the concept "food pyramid". These CAL programs do thus promote learning, some more effectively than others as I have previously discussed.

These studies have also shown that conceptual learning and methods of scientific discovery and explanation are very closely related. "Scientific" forms of activity appear to be a subset of cognitive activity. Scientific activity, however, demands more rigour on the part of the individual than is usually used in learning either in the classroom or in the "real world".

Experimentation and hypothesis-testing forms of cognitive activity are encouraged by:

1. having CAL programs structured as games with an explicit goal,
2. by allowing individuals to use CAL simulations only when they have the necessary conceptual base from which they can develop their understanding of the simulation model rather than having a "fully developed" conceptual structure before they come to use the program,
3. by providing alternative hypotheses (conceptions) whenever necessary during a program run so as to initiate some cognitive conflict and the subsequent testing of hypotheses (these were provided in POND2HELP by the questions which were asked whenever the students wanted to change the mode of the program that they were using).
The students participating in these studies exhibited forms of
cognitive activity which, at least in part, resembled Peirce's notion
of scientific methodology (page 214). There was also close agreement
between my description of the events, as well as the recognition of the
importance of surprising events, leading to conceptual learning and
those of Driver (pages 403-407). I also related "scientific" forms of
activity with the learning approach adopted by the students when using
the CAL programs. As one would expect, a "deep" learning approach was
positively correlated to "scientific" forms of cognitive activity (page
414).

The sequence of cognitive events (those which include the perception of
surprising events, with the creation of reasonable hypotheses, with
deduction and with induction) that leads to cognition may be different
depending on the level of "expertise" reached by the individual. "Lay
science", "children's science", "scientist's science" should exhibit
different sequences of cognitive events besides exhibiting the
characteristics other workers have attributed to them. It would be
interesting to examine these different areas of expertise to determine
whether they can be represented by characteristic patterns of events.
CAL programs might eventually be capable of facilitating the use of a
"high level of expertise" if these characteristic sequences can be
recognised.
11.5 Implications of these studies for the science curriculum

These studies have depended on the close examination of the use of CAL programs. My interest has been in determining what happens to the individual as s/he interacts with the learning material, and how various factors affect this interaction. This process is also an important part of curriculum development (Berman and Roderick, 1973).

I have tried to explain the learning process, in the context of CAL, and the factors that affect the process mainly by the use of my Interaction Model.

A comparison of figure 11.2a (CAL according to my Interaction Model) and figure 11.2b (a condensed form of Entwistle's model of the factors affecting learning [Entwistle, 1981]) shows that the two models have a number of similarities although Entwistle's model is concerned with learning in a wider context. Entwistle's notion of the "process" of learning is shown in my Interaction Model by the processes of perception (resulting in observation statements) and conception (resulting in conceptual statements).

Student characteristics shown in the Interaction Model are far less wide ranging only including factors such as previous knowledge and preferred strategic style, the latter encompassing expectations as to what is to be learned. I have not studied any other factors concerning the student because to do so would have complicated the research and, indeed, it would have required the devotion of too much time.
Figure 11.2  Entwistle's Model of Learning (1981) and my Interaction Model of the Student-CAL Interaction
Both of these models of learning show the student to be the centre of learning in that it is they who determine the nature of the learning task, the strategy to obtain relevant information and how this information is stored in relation to other information in memory. Such notions of learning belong to the "constructive alternativism" school of thought.

These studies have clearly shown that everyone experiences different events even when using the same CAL program. Not only are learning experiences different, but learning outcomes are also different in that a different set of concepts are acquired. Similar concepts are usually acquired in an order that is largely individualistic.

Learning is individualistic, or personal, because of the influence of various intrinsic factors such as previous knowledge, personal learning strategies etc. Piagetians also believe that the mental structure, the cognitive stage the child has reached, is an important factor which limits that which can be learnt.

Piaget (1969) sees the main purpose of education to "form the intelligence rather than to stock the memory" (page 50). Traditional forms of education are concerned with the latter rather than the former. Piaget (ibid) regards the development of the mind as being important and thus makes the following recommendations:

"Our schools owe it to themselves to develop and direct...propositional and hypothetico-deductive operations in order to use them in the development of the experimental attitude of mind and of the methods of teaching the physical sciences that will emphasise the importance of research and discovery rather than relying on mere repetition."

(page 52)
Piaget recognises that the application of his views of epistemology to science education by others (for example, Shayer and Adey [1981]) has resulted in attempts "to present the subject-matter...in forms assimilable to children of different ages in accordance with their mental structure and the various stages of development" (Piaget [1969], page 153). Shayer believes that his proposed cognitive level matching policy for the science curriculum (Shayer 1981) will lead to cognitive acceleration in those pupils. This process of cognitive acceleration seems acceptable to Piaget. However, Shayer's hopes for cognitive acceleration in scientific thinking to develop all forms of thinking might be somewhat ambitious because it does not seemingly recognise the importance of the individual nature of learning.

Piaget does not see cognitive acceleration as the sole means of promoting higher educational standards. As well as encouraging an "internal structural maturation", he believes it important "for the influences of experience and of the social and physical environment" to play their part in the development of the child (Piaget, 1969; page 169).

It thus seems as if individuals should be regarded as active participants in the learning process rather than the way behaviourists would have us believe, as passive recipients of knowledge. Student activity, rather than passivity, in the learning process is usually demanded by the very nature of the CAL-student interaction. I have shown that by participating in the active form of learning, the use of a CAL simulation causes a shift, albeit a small shift, towards a preference for active forms of learning. The initial, and marked, preference for passive forms of learning probably results from the
students' past learning experiences which have probably been those of
the normal didactic approach adopted by the majority of teachers in
secondary schools and higher forms of education.

The apparent reluctance of teachers to use an "active pedagogy" is seen
by Piaget a consequence of:

(i) The difficulty teachers have in implementing an active
pedagogy. The teacher has to provide a variety of work for the pupil
which requires much concentration on the part of the teacher. The
didactic approach is much less tiring, and is a more adult approach for
promoting learning.

(ii) The training teachers receive. There is an inadequate
knowledge of child psychology which would otherwise allow the teacher
to understand the students' learning behaviour.

Constructive alternativism adopts the view that:

"one can provide an adaptive educational system which assumes
many ways of succeeding and multiple goals from which to
choose." (Pope, 1980)

It is also a school of learning psychology which recognises that the
educational system should itself recognise the importance of individual
learning styles. The students participating in these studies appear
to have different learning goals and tasks. They appear to view the
CAL simulation in different ways based upon past experiences and their
interests.

One student (SHI) viewed the pond as if it were a fish farm. His
interests were in this area being a part-time employee on a fish farm
and also wanting to make fish farming his professional career. To
imagine the pond in the CAL simulation to be something that it isn't
does not necessarily affect what is learned when compared to others using the same simulation. However, it is probable that the learning objectives in such a situation will be different from other students using the same CAL program. "The tasks in which people engage structure to a great extent what information is selected from a situation and how that information is processed" (Posner, 1981).

CAL simulations seem to encourage the use of the imagination. After all, all that program users are doing is looking at numerical forms of data on a VDU! Use of the imagination probably means a deeper interest in the simulation being developed and perhaps thus a more intensive use of that program. Once one gets intensely interested in a learning situation, then a major hurdle has been jumped. The ability to learn, once this hurdle has been passed, is to a large extent now dependent on the possession of suitable learning strategies and an appropriate conceptual base from which growth can occur.

The students who used PONDGAME in these studies were provided with an imaginary situation, a fish farm. Such a learning situation appears to stimulate interest as shown by the greater time spent by using the program compared to those people who used the other three POND programs. The provision of a goal, in this case to make a profit, directs the learning. Posner (1981) warns, however, that if we want to understand the learning experience from the viewpoint of the student, then we must identify those goals they have and not the goals that they are given. The obvious implication for the curriculum is that in using learning objectives we are in the dangerous situation of believing that that is precisely what the knowledge the student will acquire. The curriculum should allow the necessary freedom for a
The student to acquire knowledge in a way that is natural. The rigid type of curriculum that attempts to impose a hierarchical development of knowledge is one that must be questioned.

Conceptual development, at least on the microscale examined in these studies, appears not to follow a strict hierarchy. I found that it is apparently essential to develop a suitable conceptual base (the feeding relationships of the pond organisms in these programs), but thereafter development is very much individualistic in nature. These studies also have shown that for a "deep" learning approach to be adopted, the students should possess a suitable conceptual base from which to work.

The education system should provide a curriculum which recognises and supports the view that learning is individualistic and that an "efficient" system is one that allows freedom to learn but also provides the kind of help and guidance that is required by the child/person, who cannot after all be regarded as an expert learner.

In these studies, the greatest help in learning appeared to be offered by the questions in POND2HELP. These questions provided alternatives to the concepts possessed by the students, the "truth" of which they could investigate. The questions could promote situations of cognitive conflict, with the rejection of either the "provided" concept or the "possessed" concept. In the latter situation, conceptual exchange will occur. This form of education is acceptable to constructivist thinking. Pope and Gilbert (1983) recommend a similar means of promoting conceptual exchange.
"If a teacher wishes to encourage conceptual change and acceptance of the "received view" of a scientific concept then experiences have to be arranged, within a supportive relationship, whereby the learner has his/her view challenged".

Students using POND2HELP, in accepting an alternative conception and thus deciding to enter a situation of cognitive conflict, did not appear to feel threatened. These questions did not seriously "intrude" into the learning situation for any of the students. POND2HELP also provided suggestions for investigating parts of the model when the students so requested. Again, the students did not appear to be threatened, one (DH) even seeing the program debating with him in the way that a teacher does.

A suitably designed curriculum should encourage cognitive conflict, but only when the student is prepared to have his existing views challenged. A student may be prepared to have his/her views challenged when they do not explain particular experiences, that is, those experiences which are surprising. The realisation that conceptual exchange is necessary can only occur when learning is rich in experiences that are designed to challenge existing views and, if necessary, can also provide the answers. "Answers" can, in the wider learning situation, be provided by the teacher, the necessary information can also be provided by sources such as books, periodicals, computer data bases, and even their peers.
I would suggest that this has relevance to CAL programs in that they should be capable of providing the kind of cognitive experience that encourages:

(1) the development of conceptual structures with a broad range of experience,
(2) cognitive conflict whenever inappropriate alternative conceptions appear to be held,
(3) be able to provide any necessary additional information to aid conceptual development (here the use of interactive video might play an important role).
References

Anderson, J.R. and (1973) Human Associative Memory.


Ayscough, P.B. (1973) "Computer based learning in the teaching laboratory".
Chemistry in Britain Vol.9, 61-65.

Ayscough, P.B. (1976a) "CAL - boon or burden?" Chemistry in Britain Vol.12, 348-352.


Ayscough, P.B. (1980) "Computer assisted learning in chemistry. Scope, progress, and experience".


<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Title and Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Title and Source</td>
</tr>
<tr>
<td>-----------</td>
<td>------</td>
<td>------------------</td>
</tr>
<tr>
<td>Driver, R.</td>
<td>1978</td>
<td>&quot;When is a stage not a stage?&quot; Educational Research Vol.21, 54 - 61</td>
</tr>
</tbody>
</table>


Hanson, N.R.  (1969) Perception & discovery. San Francisco. Freeman, Cooper & Co


Laurillard, D.M. (1979) "How the computer assisted learning". In Learning through Computers Tawney (Ed.)


MacDonald, B.  (1977) "The educational evaluation of
NDPCAL".  
Vol. 8, 176 - 189.

MacInnes, J.  (1981) "Through the pupil's eyes".  
School Science Review  

Byte Vol.6, 258 - 277.

Chichester. J.Wiley & Sons.

Marton, F.  (1976) "What does it take to learn?  
Some implications of an alternative view of learning".  
In Strategies for Research and Development in Higher Education.  
N.Entwistle (Ed.).  
Council for Europe.  
Pages 32 - 43.

McKeachie, W.J.  (1975) "The decline and fall of the laws of learning".  
Educational Researcher  
Vol.3, 7 - 11.

McKenzie, J.  (1977) "Computers in the teaching of undergraduate science".  

London. Jonathan Cape Ltd.

Miller, L.  (1978) "Has artificial intelligence contributed to an understanding of the human mind? A critique for and against".  

Mitchell, P.D.  (1982) "Representation of knowledge in CAL courseware".  
Computers in Education  
Vol.6, 61 - 66

Murphy, P.J.  (1975) Teacher's Guide; COEXIST, Unit on 
Population Dynamics.  
London. Edward Arnold.

Norman, D.A.  (1973) "Memory, knowledge, and the answering of questions".  
In Contemporary issues in cognitive psychology.  
R.Solso (Ed.).  
Pages 177 - 196.


Okuda, T., Tanaka, H. and Asai, K. (1978) "A formulation of fuzzy decision problems with fuzzy information using probability measures of fuzzy events".
Information & Control Vol.38, 135 - 147.


Parlett, M. (1977) "Phenomenology and educational research".
In Introduction to Illuminative Evaluation: Studies in Higher Education.
Parlett & Dearden (Eds.).

In Introduction to Illuminative Evaluation: Studies in Higher Education.
Parlett & Dearden (Eds.).

Acta Psychologica Vol.32, 301 - 345

Pascual-Leone, J. (1976) "On learning and development, Piagetian style: A reply to Lefebvre-Pinard".

Pask, G. (1961) "Machines that teach".
New Scientist Vol.16, 308 - 311.
Pask, G. (1969) "Computer assisted learning and teaching". 
Proc. of a seminar on CBL systems 
Leeds University.

Pask, G. (1976a) "Conversational techniques in the study and practice of education". 

Pask, G. (1976b) "Styles and strategies of learning" 

Peirce, C.S. 
Hartshorne & Weiss (Eds.).
(1931-35) 
Vols. 7 - 8. 
Burks (Ed.) (1958). 
Cambridge, Mass.

In Forms of intellectual and ethical development in the college years. 
New York. Holt, Rinehart & Winston

Piaget, J. (1968) Structuralism 

Translation first published 1971. 
London. Longman.


M. Grene (Ed.). 
University of Chicago Press.

Paper presented at University of Osnabrück.


Shirley, R. (1978) "Graphical displays for CAL".
In Interactive Computer Graphics in Science Teaching.
McKenzie, Elton, Lewis (Eds.) Chichester. Ellis Horwood Ltd.

Skinner, B.F. (1958) "Teaching Machines".
Science Vol.128, 969 - 977

Simons, H. (1977) "Case-studies of innovation"
In Beyond the numbers game.
Hamilton et al (Eds.) MacMillan Education.

Smith, L.M. (1977) "Integrating participant observation into broader evaluation strategies".
In Beyond the numbers game.
Hamilton et al (Eds.) MacMillan Education.


Swift, D. (1981) "Another brick in the wall...? Student's conceptions of science and scientific method".
Paper presented at the PCKG, Institute of Educational Development, University of Surrey.

Terhardt, E. (1981) "Interpretative approaches in education research".

Lamson Technical Products Ltd.

Trantner, J.A. and Leveridge, M.E. (1978) "Fond Ecology"
In Computers in the Biology Curriculum.
School's Council.
London. Edward Arnold.
Pages 55 - 70.

Vinacke, (1952) Psychology of Thinking
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wederkind, J.</td>
<td>1977</td>
<td>&quot;The instructional use of a graphic interactive programming system: GRIPS&quot;.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Symposium on Computer Assisted Learning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University of Surrey.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Page A8(i).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monash University, Australia.</td>
</tr>
<tr>
<td>West, L.H.T., Garrard, J. and Fensham, P.J.</td>
<td>1982</td>
<td>&quot;Intended cognitions in science teaching&quot;.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The Australian Science Teachers Journal Vol.28, 5 - 12.</td>
</tr>
<tr>
<td>White, R.T.</td>
<td>1974</td>
<td>&quot;The validation of a learning hierarchy&quot;.</td>
</tr>
<tr>
<td>Wildman, T.M.</td>
<td>1981</td>
<td>&quot;Cognitive theory and the design of instruction&quot;.</td>
</tr>
<tr>
<td>Witkin, H.A.</td>
<td>1976</td>
<td>&quot;Cognitive style in academic performance and in teacher-student relations&quot;.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Computers in the Life Sciences. R.Lewis (Ed.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pages 85 - 93.</td>
</tr>
<tr>
<td>Zinn K.L.</td>
<td>1978</td>
<td>&quot;An overview of current developments in CAL in the U.S.&quot;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Programmed Learning and Educational Technology Vol.15, 126 - 135</td>
</tr>
</tbody>
</table>
Appendix 1a

Students participating in these studies who used POND-2

<table>
<thead>
<tr>
<th>Initials</th>
<th>Sex</th>
<th>Age</th>
<th>GCE A/L subjects studying</th>
<th>Year of course</th>
<th>Previous ecology experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW</td>
<td>M</td>
<td>16</td>
<td>Botany, Chemistry, Physics</td>
<td>1</td>
<td>O/L Biology, mother is a biology teacher</td>
</tr>
<tr>
<td>GU</td>
<td>M</td>
<td>16</td>
<td>Botany, Zoology, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>ST</td>
<td>F</td>
<td>16</td>
<td>Botany, Zoology</td>
<td>1</td>
<td>O/L Biology + ecology project.</td>
</tr>
<tr>
<td>PS</td>
<td>M</td>
<td>17</td>
<td>Botany, Zoology, Physics, Computing</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SHI</td>
<td>M</td>
<td>18</td>
<td>Botany, Zoology, Chemistry, Geography</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>NP</td>
<td>F</td>
<td>19</td>
<td>Botany, Zoology</td>
<td>1</td>
<td>O/L Biology + ecology work in Africa</td>
</tr>
<tr>
<td>TS</td>
<td>F</td>
<td>19</td>
<td>Botany, Zoology</td>
<td>2</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>PN</td>
<td>M</td>
<td>20</td>
<td>Botany, Zoology, Chemistry</td>
<td>2</td>
<td>School Certificate (Africa)</td>
</tr>
<tr>
<td>MW</td>
<td>F</td>
<td>18</td>
<td>Biology, Chemistry, Statistics</td>
<td></td>
<td>Revision A/L Biology</td>
</tr>
</tbody>
</table>
### Appendix 1b

**Students participating in these studies who used PONDQU**

<table>
<thead>
<tr>
<th>Initials</th>
<th>Sex</th>
<th>Age</th>
<th>GCE A/L subjects studying</th>
<th>Year of course</th>
<th>Previous ecology experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>JB</td>
<td>F</td>
<td>19</td>
<td>Maths. Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>CP</td>
<td>M</td>
<td>19</td>
<td>Chemistry Botany Zoology</td>
<td>2</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SA</td>
<td>F</td>
<td>20</td>
<td>Zoology Chemistry</td>
<td>1 &amp; 2</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SW</td>
<td>M</td>
<td>17</td>
<td>Physics Chemistry Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>AB</td>
<td>M</td>
<td>19</td>
<td>Physics Chemistry Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>AR</td>
<td>F</td>
<td>17</td>
<td>Physics Chemistry Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>RR</td>
<td>F</td>
<td>17</td>
<td>Physics Chemistry Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SH2</td>
<td>F</td>
<td>21</td>
<td>Physics Maths. Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>JH1</td>
<td>M</td>
<td>17</td>
<td>Physics Chemistry Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
</tbody>
</table>
### Appendix 1c

**Students participating in these studies who used PONDGAME**

<table>
<thead>
<tr>
<th>Initials</th>
<th>Sex</th>
<th>Age</th>
<th>GCE A/L subjects studying</th>
<th>Year of course</th>
<th>Previous ecology experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>JH2</td>
<td>M</td>
<td>22</td>
<td>Chemistry, Zoology</td>
<td>1 &amp; 2</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>AY</td>
<td>M</td>
<td>19</td>
<td>Biology, Chemistry, Physics</td>
<td></td>
<td>Revision A/L Biology</td>
</tr>
<tr>
<td>AM</td>
<td>M</td>
<td>18</td>
<td>Maths, Chemistry, Physics, Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>RCM</td>
<td>M</td>
<td>17</td>
<td>Chemistry, Maths, Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SE</td>
<td>F</td>
<td>19</td>
<td>Chemistry, Maths, Zoology</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>CH</td>
<td>F</td>
<td>25</td>
<td>Physics, Chemistry, Zoology</td>
<td>1</td>
<td>A/L Biology</td>
</tr>
<tr>
<td>HS</td>
<td>F</td>
<td>18</td>
<td>Zoology, Botany, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
</tbody>
</table>
### Appendix 1d

**Students participating in these studies who used POND2HELP**

<table>
<thead>
<tr>
<th>Initials</th>
<th>Sex</th>
<th>Age</th>
<th>GCE A/L subjects studying</th>
<th>Year of course</th>
<th>Previous ecology experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>M</td>
<td>18</td>
<td>Chemistry, Zoology, Botany, Economics</td>
<td>1</td>
<td>O/L Biology &amp; Environmental Sci.</td>
</tr>
<tr>
<td>SDT</td>
<td>M</td>
<td>17</td>
<td>Botany, Zoology, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>FQ</td>
<td>F</td>
<td>21</td>
<td>Botany, Zoology, Physics, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>DG</td>
<td>M</td>
<td>17</td>
<td>Botany</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>SB</td>
<td>M</td>
<td>18</td>
<td>Botany, Zoology, Chemistry</td>
<td>1</td>
<td>A/L Biology</td>
</tr>
<tr>
<td>RC2</td>
<td>M</td>
<td>18</td>
<td>Botany, Zoology, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>DC</td>
<td>M</td>
<td>16</td>
<td>Botany, Zoology, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>PP</td>
<td>F</td>
<td>16</td>
<td>Zoology, Physics, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>NL</td>
<td>F</td>
<td>16</td>
<td>Physics, Chemistry, Zoology, Maths.</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
<tr>
<td>DH</td>
<td>M</td>
<td>16</td>
<td>Zoology, Physics, Chemistry</td>
<td>1</td>
<td>O/L Biology</td>
</tr>
</tbody>
</table>
The British Peppered Moth, *Biston betularia*, exists in a grey form, which is remarkably well adapted to resemble the lichen on the bark of trees, so that it cannot be readily seen by bird predators. About 1850, a black pigmented variety (melanic form) was first seen in the Manchester area. This form is very conspicuous against the lichen covered bark of trees.

**4.1 In which direction would you expect selection to act, that is, which form will be most predated?**

However, the melanic form was not eliminated by selection. In fact, by 1900 the proportion of the melanic form to the non-melanic form by 99:1 in the Manchester area. By this time the Industrial Revolution had greatly changed the character of much of the countryside. From industrial centres such as Manchester and Birmingham, a vast amount of soot and other waste products poured from factory chimneys, polluting the surrounding areas. The white, lichen covered trees were becoming black.

**4.2 Which form of moth is at an advantage now and why?**

Kettlewell found (by making direct comparisons of the number of moths eaten by birds in different areas) that in industrial areas the melanic form was far less heavily predated, as the birds, hunting by sight, could not see it so easily (see figure 1).

Study figure 2.

**4.3 Where are the main industrial areas of Britain? Compare them with the distribution of the two forms of the moth.**

**4.4 What selective factors are operating on each form of the moth?**

**4.5 Which allele (light or dark) is at an advantage in each environment?**
Map showing the distribution of melanic and grey peppered moths, *Biston betularia* in 1952-56.
Computer: Commodore "Pet".

Instructions for use of computer:
Switch computer on.
Place tape in cassette deck.
Type LOAD "EVOLU", then press "RETURN".
Press "play" on cassette deck.
When the programme has been loaded type RUN, and press RETURN.

Instructions for use of Programme:
The programme "EVOLU" studies a population of peppered moths for thirty years. You can select a mutation rate for the appearance of dark moths from the light coloured form, you can select the initial number of light moths, you can change the environment to favour light or dark coloured moths and select a year when the environment changes to favour light or dark moths.

(i) Attempt to show changes in number of light and dark coloured moths in
   (a) a rural area,
   (b) a rural area with new industrial development,
   (c) an industrial area,
   (d) an industrial area becoming a smokeless zone.

(ii) You can attempt to determine the effect of different mutation rates in the above environments.
<table>
<thead>
<tr>
<th>Student action</th>
<th>Student comments</th>
<th>Teacher help</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Would be appreciated if you would complete this form very carefully since your comments will be taken into account in the design of future packages.

Did you enjoy working with the package?

Did you think the package worth doing?

Did you learn anything? YES/NO

Please elaborate if your answer to question 3 was YES.

Is there anything that you feel is still unclear? YES/NO

Please elaborate if your answer to question 5 was YES.

Did you feel that this mode of learning was any better than a normal laboratory practical or tutorial? YES/NO

Please elaborate if your answer to question 7 was YES.

Any further comments?

Thank You.
It would be appreciated if you would complete this form very carefully since your comments will be taken into account in the future development of Computer Assisted Learning packages. These CAL packages may replace some of your laboratory practicals, tutorials and perhaps lectures in the near future!

1. Did you enjoy your practical or tutorial? 
   - [ ] very much 
   - [ ] not at all

2. Did you think the practical/tutorial worth doing? 

3. Did you learn anything? 
   - YES/NO

4. Please elaborate if your answer to question 3 was YES.

5. Is there anything that you feel is still unclear? 
   - YES/NO

6. Please elaborate if your answer to question 5 was YES.

7. Do you think that the session could be improved in any way? 
   - YES/NO

8. Please elaborate if your answer to question 7 was YES.

9. Any further comments?

Thank You.
APPENDIX 6

EVOLUTION ASSESSMENT
1. When looking for peppered moths in a given area, where would you expect to find them?

2. What is the name of the process which causes light moths to produce dark moths?

3. What is the name of the dark pigment found in these moths?

4. When, approximately, did dark moths first appear in considerable numbers in this country?

5. What are the natural predators of peppered moths?

6. Why are light moths predated upon more frequently than dark moths in a smoke polluted area?
7. Where would you expect to find the highest proportion of dark moths?
   a) Devon,
   b) Manchester,
   c) Guildford,
   d) Southend.

   Tick appropriate box..... a b c d

8. Why did you give your answer to question number 7?

9. Imagine an area of the country where there is no industry.

   Would you find more light moths? 
   dark moths? 

   If a firm now sets up a factory in this area and burns a lot of coal, would

   light moths increase? 
   dark moths increase? 
   numbers of light and dark moths stay constant?
APPENDIX 7a

POND-2 PROTOCOL SHEETS USED FOR JUDGING COGNITIVE LEVELS
<table>
<thead>
<tr>
<th>STUDENT ACTION</th>
<th>STUDENT COMMENTS</th>
<th>TEACHER HELP OFFERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input to vary pond life (ie, mode 2).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input to have graphical display of results.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial numbers input: phytoplankton...125</td>
<td>How big is the pond? It does depend on the size of the pond. A small pond can only hold a few fish. There is not much food in the pond.</td>
<td></td>
</tr>
<tr>
<td>herbivores...20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input 50 fish.</td>
<td>Examine graph displayed.</td>
<td></td>
</tr>
<tr>
<td>Input 1 (to observe the pond).</td>
<td>Examine results.</td>
<td></td>
</tr>
<tr>
<td>Why are there fewer fish in March?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perhaps it is the food.</td>
<td>Fish eat herbivores, less to eat in March.</td>
<td></td>
</tr>
<tr>
<td>Peak time in August, no May.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shall we write this down somewhere?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak there (pointing to April) and there (June), drop in May.</td>
<td>Lot of fish causing the drop in herbivores.</td>
<td></td>
</tr>
<tr>
<td>They are all integrated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What makes the fish population fall?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All interrelated with the seasons. Food chains.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Input to use mode 2.</td>
<td>If we put more phytoplankton in, there will be more food for the fish.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The initial numbers are for January which is a cold month. There should be fewer of every thing.</td>
<td></td>
</tr>
<tr>
<td>Input 100 phytoplankton</td>
<td>10 herbivores 250 fish</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input tabular display of results. Examine results.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Where is it peaking? *</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Same as before.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A month after it. High during the summer. It goes right down there. * Is it (fish) high because we started with a high number?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Why the drop in March?</td>
<td>Yes.</td>
</tr>
<tr>
<td></td>
<td>Cold in march.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Large drop there (pointing to phytoplankton) followed by a drop in the numbers of fish.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input to continue to year 2.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>We have started with too many.</td>
<td>You can see what happens when you overstock a pond. Yes.</td>
</tr>
<tr>
<td></td>
<td>Will it become stable?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It doubled in one month (April to May).</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There should be a drop in the herbivores.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Input to continue to year 3.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It (the population) should be stabilising. It has stabilised out a bit.</td>
<td></td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Input 250 phytoplankton, 10 herbivores, 250 fish.</td>
<td>In the previous year there was a high in April, it is high in May here.</td>
<td>No, it was in May. Why not, this time, have a high initial phytoplankton population?</td>
</tr>
<tr>
<td>Input 0 phytoplankton, 10 herbivores, 250 fish.</td>
<td>If we will keep the numbers of fish and herbivores the same, there should be a general increase in the populations. Should be more fish. We have got less fish. Not an awful lot. What do phytoplankton feed on? They are plants! If you put a lot of herbivores in the pond, there are less fish. Start again. What happens when there are no phytoplankton?</td>
<td>What has happened?</td>
</tr>
<tr>
<td>Input to continue...</td>
<td>Oooh! Fish still living. The herbivores do not last for ever. Let us continue to year 2. Fish last quite a long time. Are they eating the smaller fish? What happens when there is 1 phytoplankton? What happens when there are no fish? Make it one fish...</td>
<td></td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>----------------</td>
<td>------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Input 250 phytoplankton</td>
<td>Fish has gone already. There should be a general increase in the herbivores.</td>
<td>Have a look at your package notes.</td>
</tr>
<tr>
<td>10 herbivores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 fish</td>
<td>There is not.</td>
<td></td>
</tr>
<tr>
<td>Examine results.</td>
<td>I wonder why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>There are less phytoplankton and herbivores.</td>
<td></td>
</tr>
<tr>
<td>Input to continue to year 2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input to start again.</td>
<td>Try on low pollution then high. Start the pollution in January.</td>
<td></td>
</tr>
<tr>
<td>Input mode 4 (pollution)</td>
<td>Why the massive increase in phytoplankton in February? Going down. Probably dying off.</td>
<td></td>
</tr>
<tr>
<td>Input 1.</td>
<td>Why such an increase initially?</td>
<td></td>
</tr>
<tr>
<td>Examined results.</td>
<td>Pollution is by fertilisers. Low concentrations would be beneficial.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Go to: year 2.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concentration should be higher. Are they adapting to it?</td>
<td>You polluted the pond in the first month.</td>
</tr>
<tr>
<td></td>
<td>So it is disappearing!</td>
<td></td>
</tr>
</tbody>
</table>

- 492 -
<table>
<thead>
<tr>
<th>STUDENT ACTION</th>
<th>STUDENT COMMENTS</th>
<th>TEACHER HELP OFFERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input to have a different level of pollution.</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Input high level of pollution.</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>Look at results.</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Input high level of pollution.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input pond polluted in month 5.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Should be an increase, then a decrease. Might even be a dramatic increase.</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>The pollution kills everything.</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Herbivores back now.</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Fish might come back.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input to continue to year 2.</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>Let us see when the fish come back.</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Input to continue to year 3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No fish yet.</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>It is almost the same as when we put no fish at all.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input mode 3(fishing).</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>Input 20 fishermen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going to be more herbivores when there are less fish.</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Fishing frequency = ?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If say 4 or 5, fishing is once a week, that is every weekend.</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>=4.</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Close season = ?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close season is when they are breeding.</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>= months 3 to 5.</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Why sudden drop in August?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If take fish away the phytoplankton and herbivores should rise in numbers.</td>
<td>73</td>
<td></td>
</tr>
</tbody>
</table>

- 493 -
<table>
<thead>
<tr>
<th>STUDENT ACTION</th>
<th>STUDENT COMMENTS</th>
<th>TEACHER HELP OFFERED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A lot of people come fishing after the close season.</td>
<td>Herbivores do not increase because wrong time of year.</td>
</tr>
<tr>
<td>Input to continue to year 2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>If less fish, they (fishermen) are going to catch less.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 7b

PREY PROTOCOL SHEETS USED FOR JUDGING COGNITIVE LEVELS
<table>
<thead>
<tr>
<th>STUDENT ACTION</th>
<th>STUDENT COMMENTS</th>
<th>TEACHER HELP OFFERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input 400 prey</td>
<td>Use 400. Why? It is the maximum number.</td>
<td></td>
</tr>
<tr>
<td>Input 10.</td>
<td>What is the prey cover? Other student explains after recalling the description given earlier in the programme.</td>
<td></td>
</tr>
<tr>
<td>Input prey increase of 5.</td>
<td>Predator death? 5. Nothing will happen if 5. If 3, more predator increase than death.</td>
<td></td>
</tr>
<tr>
<td>Input predator death of 3.</td>
<td>Examine output. They are just units.</td>
<td></td>
</tr>
<tr>
<td>Examine output.</td>
<td>What is time axis in? It is evening out.</td>
<td></td>
</tr>
<tr>
<td>Input &quot;yes&quot;.</td>
<td>Try 300, see what 2 of previous is.</td>
<td></td>
</tr>
<tr>
<td>Input 300 prey.</td>
<td>Same number, 5? No, change it and see what it is.</td>
<td></td>
</tr>
<tr>
<td>Input 40 predators.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input prey increase = 3</td>
<td>Prey cover 80</td>
<td></td>
</tr>
<tr>
<td>Input predator death = 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input prey cover = 80</td>
<td>Observe output on VDU. Going up bit by bit. The predators are staying the same now at 27.</td>
<td></td>
</tr>
<tr>
<td>Input to change cover and rates.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Prey cover=0</td>
<td>10 before that. Don't have to have any prey cover at all. Must be some surviving. Not necessarily!</td>
<td>Cited example where no prey cover would exist.</td>
</tr>
<tr>
<td>Input prey increase of 7.</td>
<td>Prey will not increase. But if we had enough increase will reproduce faster than can get eaten.</td>
<td>22</td>
</tr>
<tr>
<td>Input predator death of 10</td>
<td>See if we can kill out the predators.</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Observe the output.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Get sharp increase there, where multiplying quickly, the decrease when get eaten. Then probably stay regular. Haven't died off yet. Moving constantly. Predators dying off more than the prey. So the prey have still got a chance to survive while the predators dying off.</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>The predator numbers are oscillating.</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Let us change everything now.</td>
<td></td>
</tr>
<tr>
<td>Input number of prey=100</td>
<td>100? Have a small number of predators.</td>
<td>30</td>
</tr>
<tr>
<td>Input number of predators =200.</td>
<td>Let us have more predators than prey to see if the prey get eaten.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cannot have more prey cover than prey. If we make death rate of the predators high, should keep the prey.</td>
<td>33</td>
</tr>
<tr>
<td>Input prey cover=10</td>
<td>High number of predators then high death rate as well.</td>
<td>35</td>
</tr>
<tr>
<td>Input prey increase=9</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Input predator death rate = 5</td>
<td>It will probably go whizzing off the screen.</td>
<td></td>
</tr>
<tr>
<td>Observe the output.</td>
<td>Starts high then goes right down. It is oscillating again.</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Still balancing again. Staying the same.</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>It is a balanced ecosystem. Stable ecosystem?</td>
<td>40</td>
</tr>
<tr>
<td>Input to change cover and rates.</td>
<td>We had a cover of 10 last time.</td>
<td>41</td>
</tr>
<tr>
<td>Input cover rate of 5.</td>
<td>You want to see them get eaten!</td>
<td>42</td>
</tr>
<tr>
<td>Input prey increase = 1.</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>Input predator death rate = 9.</td>
<td>I hope they get eaten.</td>
<td>44</td>
</tr>
<tr>
<td>Observe output.</td>
<td>The predators have died out. Why the predators and not the prey?</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Nothing to stop the prey. They died out because the predator death rate was too high.</td>
<td>46</td>
</tr>
<tr>
<td>Input predator death rate = 1</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>Observe output.</td>
<td>Still did not kill the prey off. The predators are still dying off. You still cover.</td>
<td>48</td>
</tr>
<tr>
<td>Input prey cover = 0</td>
<td>Keep both at their minimum.</td>
<td>49</td>
</tr>
<tr>
<td>Input prey increase = 1</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Input predator death rate = 1</td>
<td>Observed output.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Killed both off. The predators have got nothing to eat, so that is it.</td>
<td>51</td>
</tr>
<tr>
<td>Input number of prey = 200</td>
<td>Let us see if we can get it to balance again.</td>
<td>52</td>
</tr>
<tr>
<td>Input number of predators = 150</td>
<td>Both will die off if we have no prey cover.</td>
<td>53</td>
</tr>
<tr>
<td>Input prey cover = 200</td>
<td></td>
<td>54</td>
</tr>
<tr>
<td>STUDENT ACTION</td>
<td>STUDENT COMMENTS</td>
<td>TEACHER HELP OFFERED</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-------------------------------------------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>Input prey increase=1</td>
<td>Plenty of prey</td>
<td></td>
</tr>
<tr>
<td>Input predator death</td>
<td>Others should go up</td>
<td>No, is surprising.</td>
</tr>
<tr>
<td>rate=1</td>
<td></td>
<td>Cover rate of 200, have 209</td>
</tr>
<tr>
<td></td>
<td></td>
<td>prey, therefore 9 for 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>predators to eat.</td>
</tr>
<tr>
<td>Observed output</td>
<td></td>
<td>Keeps constant.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Want to get the largest no.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of prey and predators</td>
</tr>
<tr>
<td></td>
<td></td>
<td>without them dying off.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If you increase the prey</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cover there is less to eat.</td>
</tr>
<tr>
<td>Input prey cover=200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prey increase=?</td>
<td>If we have a high number the prey will go up, then we will be able to balance it.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>I bet one of them dies out.</td>
</tr>
<tr>
<td>Input 9 Input predator death=3</td>
<td></td>
<td>Stable at higher predator level, lower prey number.</td>
</tr>
<tr>
<td>Observed output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input prey number=50</td>
<td></td>
<td>No, predators will die out.</td>
</tr>
<tr>
<td>Predator no.=?</td>
<td></td>
<td>Going to go shooting up, so maust have more predators.</td>
</tr>
<tr>
<td>Input 100</td>
<td></td>
<td>Predators are dying off.</td>
</tr>
<tr>
<td>Input prey increase=10</td>
<td></td>
<td>More predators than prey.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 8a

LISTING OF POND-2
10 PRINT "WHAT IS THE TIME";
11 INPUT TI$
40 OPEN 1,4
41 PRINT#1,"TIME=";TI$
50 LET R9=2
60 FOR A=1 TO 5:PRINT#1: NEXT A
90 PRINT#1," POND-2"
100 PRINT#1,"
110 DIM M$(2),R$(3)
120 GOTO 170
130 PRINT#1,"MODE?"
131 PRINT"MODE";
140 INPUT M$:PRINT#1,M6
150 IF (M6-1)*(M6+2)*(M6-3)*(M6-4)<0 THEN 170
160 GOTO 300
170 PRINT#1, " YOU CAN:-"
180 PRINT"J" YOU CAN:-
190 PRINT#1,"MODE 1 OBSERVE THE POND"
200 PRINT"MODE 1 OBSERVE THE POND"
210 PRINT#1,"MODE 2 SET INITIAL NUMBERS OF PHYTOPLANTON,HERBIVORES AND FISH."
220 PRINT"MODE 2 SET INITIAL NUMBERS OF"
230 PRINT " PHYTOPLANTON,HERBIVORES AND FISH."
230 PRINT#1,"MODE 3 CATCH FISH"
240 PRINT"MODE 3 CATCH FISH"
250 PRINT#1,"MODE 4 POLLUTE THE POND"
260 PRINT"MODE 4 POLLUTE THE POND"
270 PRINT#1,"TYPE 1,2,3 OR 4?"
280 PRINT"TYPE 1,2,3 OR 4";
290 GOTO 140
300 R=0:U=0:U1=0:M9=0:P=1E+11:H=3.5E+07:F=1000
310 IF M6=4 THEN 350
320 PRINT#1,"DO YOU WANT GRAPHICAL(1) OR TABULAR(2) OUTPUT?"
330 PRINT"DO YOU WANT GRAPHICAL(1) OR TABULAR(2) OUTPUT?"
340 INPUT ZZ:PRINT#1,ZZ: GOTO 360
350 ZZ=2
360 IF M6<2 THEN 660
370 PRINT#1,"WHAT ARE THE INITIAL NUMBERS OF"
380 PRINT"WHAT ARE THE INITIAL NUMBERS OF"
390 PRINT#1, "PHOTOPLANKTON(0-250)X1,000,000,000?"
400 PRINT"PHOTOPLANKTON(0-250)X1,000,000,000"
410 INPUT P: PRINT#1, P
420 IF P*(250-P)<0 THEN 460
430 PRINT#1,"***NOT MORE THAN 250 NOR LESS THAN 0?"
440 PRINT"***NOT MORE THAN 250 NOR LESS THAN 0"
450 GOTO 410
460 LET P=P*1E+09
470 PRINT#1,"HERBIVORES(0-50)X1,000,000?"
480 PRINT"HERBIVORES(0-50)X1,000,000"
490 INPUT H: PRINT#1, H
500 IF H*(50-H)<0 THEN 540
510 PRINT#1,"***NOT MORE THAN 50 NOR LESS THAN 0?"
520 PRINT"***NOT MORE THAN 50 NOR LESS THAN 0"
530 GOTO 490
540 LET H=H*1E+06
550 PRINT#1,"FISH(0-1000)?"
560 PRINT"FISH(0-1000)"
570 INPUT F: PRINT#1, F
580 IF INT(F)=F THEN 620
590 PRINT"***YOU CAN ONLY HAVE COMPLETE FISH?"
600 PRINT#1,"***YOU CAN ONLY HAVE COMPLETE FISH?"
610 GOTO 570
620 IF F*(1000-F)<0 THEN 660
630 PRINT"***NOT MORE THAN 1000 NOR LESS THAN 0"
640 PRINT#1,"***NOT MORE THAN 1000 NOR LESS THAN 0"
650 GOTO 550
660 IF M<4 THEN 860
670 PRINT#1,"WHAT LEVEL OF POLLUTION"
680 PRINT"WHAT LEVEL OF POLLUTION"
690 PRINT#1,"LOW (1), MODERATE (2) OR HIGH (3)?"
700 PRINT"LOW (1), MODERATE (2) OR HIGH (3)?"
710 INPUT U: PRINT#1, U
720 IF (U-1)*(U-2)*(U-3)=0 THEN 760
730 PRINT#1,"***TYPE 1, 2 OR 3"
740 PRINT"***TYPE 1, 2 OR 3"
750 GOTO 710
760 PRINT#1,"WHEN DOES IT START?"
770 PRINT "WHEN DOES IT START?"
780 INPUT U4:PRINT #1, U4
790 IF U4 > INT(U4) THEN 810
800 IF (U4-1)*(12-U4) = 0 THEN 840
810 PRINT #1, "***GIVE THE MONTH NUMBER, EG. 3 FOR MARCH"
820 PRINT "***GIVE THE MONTH NUMBER, EG. 3 FOR MARCH"
830 GOTO 780
840 LET U5 = U4 + 1
850 LET U1 = 1
860 LET A = 0
870 LET M4 = 0
880 LET M5 = 0
890 IF M6 <> 3 THEN 1320
900 PRINT #1, "HOW MANY FISHERMEN (0-20)?"
910 PRINT "HOW MANY FISHERMEN (0-20)?"
920 INPUT A:PRINT #1, A
930 IF A = INT(A) THEN 970
940 PRINT #1, "***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
950 PRINT "***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
960 GOTO 900
970 IF A * (20 - A) = 0 THEN 1010
980 PRINT #1, "***NOT MORE THAN 20 NOR LESS THAN 0 FISHERMEN"
990 PRINT "***NOT MORE THAN 20 NOR LESS THAN 0 FISHERMEN"
1000 GOTO 900
1010 IF A = 0 THEN 1320
1020 PRINT #1, "FISHING FREQUENCY?"
1030 PRINT "FISHING FREQUENCY?"
1040 INPUT A1:PRINT #1, A1
1060 PRINT #1, "***YOU CAN FISH 1, 2 OR 4 TIMES A MONTH"
1070 PRINT "***YOU CAN FISH 1, 2 OR 4 TIMES A MONTH"
1080 FOR A1 = 1 TO 4: NEXT
1090 GOTO 1040
1100 LET A2 = 4
1110 IF A1 > 2 THEN 1140
1120 LET A2 = 2
1130 GOTO 1160
1140 IF A1 > 4 THEN 1160
1150 LET A2 = 1
1160 PRINT #1,
1170 PRINT #1, "WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1180 PRINT"WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1190 PRINT#1,"GIVE THE MONTH NUMBER #G.3 FOR MARCH"
1200 PRINT"GIVE THE MONTH NUMBER #G.3 FOR MARCH"
1210 PRINT#1,"FIRST MONTH?"
1220 PRINT"FIRST MONTH?"
1230 INPUT M4:PRINT#1,M4
1240 IF M4=0 THEN 1320
1250 IF M4<INT(M4) THEN 1190
1260 IF (M4-1)*(-12-M4)<0 THEN 1190
1270 PRINT#1,"LAST MONTH?"
1280 PRINT"LAST MONTH?"
1290 INPUT M5:PRINT#1,M5
1300 IF M5>INT(M5) THEN 1190
1310 IF (M5-1)*(-12-M5)<0 THEN 1190
1320 IF ZZ<1 THEN 310
1330 IF ZZ<2 THEN 310
1340 LET M9=M9+1
1350 IF ZZ=2 THEN 1370
1360 GOTO 1390
1370 GOSUB 3830
1380 GOTO 1400
1390 GOSUB 3180
1400 IF R3=2 THEN 1560
1410 IF R3<1 THEN 1550
1420 PRINT#1,"DEC":CHR$(141);TAB(8);".";CHR$(141)
1430 PRINT#1,TAB(P9);"P":CHR$(141)
1440 IF P9<H9 THEN 1470
1450 PRINT#1,TAB(H9);"*":CHR$(141)
1460 GOTO1480
1470 PRINT#1,TAB(H9);"H":CHR$(141)
1480 IF F9<P9 THEN 1510
1490 PRINT#1,TAB(F9);"*":CHR$(141)
1500 GOTO 1550
1510 IF F9>H9 THEN 1540
1520 PRINT#1,TAB(F9);"*":CHR$(141)
1530 GOTO 1550
1540 PRINT#1,TAB(F9);"F"
1550 GOSUB 4310
1560 LET M2=0
1570 LET M=0
1580 LET A8=0
1590 RESTORE
1600 LET I=0
1610 LET A7=0
1620 LET M=M+1
1630 LET M1=0
1640 LET I=I+1
1650 LET M1=M/I+7
1660 LET S=SIN((M*28+M1-78)*0.0187)
1670 IF H>0 THEN 1710
1680 LET H1=0
1690 LET H2=0
1700 GOTO 1870
1710 LET H1=P/H
1720 IF H1>7000 THEN 1760
1730 IF H1<100 THEN 1780
1740 LET H1=4000*(H1-100)/6900
1750 GOTO 1790
1760 LET H1=4000
1770 GOTO 1790
1780 LET H1=0
1790 LET H2=P/1000
1800 IF H2>1E+07 THEN 1840
1810 IF H2<100 THEN 1860
1820 LET H2=(H2-1000)/9.999E+06
1830 GOTO 1870
1840 LET H2=1
1850 GOTO 1870
1860 LET H2=0
1870 LET H3=M1*M2
1880 LET H4=M1*M2
1890 IF F>0 THEN 1920
1900 LET F1=0
1910 GOTO 2020
1920 IF F>.1 THEN 1940
1930 LET F=.1
1940 LET F1=F/H
1950 IF F1>200 THEN 1990
1960 IF F1<20 THEN 2010
1970 LET F1=100*(F1-20)/100
1980 GOTO 2020
1990 LET F1=100
2000 GOTO 2020
2010 LET F1=0
2020 LET S1=S*1E+10+1.4E+11
2030 LET S2=S+4
2040 LET P1=(P-H4/1.8)*.45
2050 IF(P+P1)/2<=S1 THEN 2100
2060 LET P2=(P+P1)/2-S1
2070 LET S2=S2-(S2-1)*P2/S1
2080 IF S2>1 THEN 2100
2090 LET S2=1
2100 LET P=P1*S2
2110 IF U1=0 THEN 2170
2120 IF (M-U4)*(M-U5)<0 THEN 2170
2130 IF U=3 THEN 2160
2140 LET P=P*4
2150 GOTO 2170
2160 LET P=P/4
2170 IF P>0 THEN 2190
2180 LET P=0
2190 LET H=(H-F*F1*20)*(H1*.000045+.8)*(H3*.00005+1)
2200 IF U1=0 THEN 2240
2210 IF U=1 THEN 2240
2220 IF (M-U4)*(M-U5)<0 THEN 2240
2230 LET H=H/2
2240 IF H>0 THEN 2260
2250 LET H=0
2260 LET F7=.97
2270 IF (M-4)*(10-M)<0 THEN 2290
2280 LET F7=F7-F7*.00017
2290 LET F6=F*F7
2300 IF (M-4)*(M-5)<0 THEN 2370
2310 IF F<3000 THEN 2350
2320 IF F>4000 THEN 2370
2330 LET F8=1-((F-3000)/1000
2340 GOTO 2380
2350 LET F8=1
2360 GOTO 2380
2370 LET F8=0
2380 LET F=F6*(1+F8*F1*.003)
2390 IF U=0 THEN 2420
2400 IF (M-U4)*(M-U5)<0 THEN 2420
2410 LET F=F/U/1.28
2420 IF F>=1 THEN 2440
2430 LET F=0
2440 LET M3=0
2450 IF A=0 THEN 2660
2460 IF M4=M5 THEN 2490
2470 IF (M-M4)*(M5-M)<0 THEN 2520
2480 GOTO 2500
2490 IF (M-M4)*(M5-M)<0 THEN 2520
2500 LET M3=1
2510 GOTO 2660
2520 LET M2=M2+1
2530 IF A2=M2 THEN 2660
2540 LET M2=0
2550 IF F>4000 THEN 2590
2560 IF F<50 THEN 2610
2570 LET R3=25*(F-50)/3350
2580 GOTO 2620
2590 LET R3=25
2600 GOTO 2620
2610 LET R3=0
2620 LET R3=R3*2*RND(0)
2630 LET R6=R3*R
2640 LET R7=R7+R6
2650 LET F=F-R6
2660 IF M1<28 THEN 1640
2670 GOSUB 3390
2680 IF I<48 THEN 1610
2690 IF M6>3 THEN 2780
2700 IF A8>0 THEN 2740
2710 PRINT#1,"NO FISH CAUGHT DURING THE YEAR"
2720 PRINT#1,"NO FISH CAUGHT DURING THE YEAR"
2730 GOTO 2780
2740 PRINT#1,"NUMBER OF FISH CAUGHT DURING"
2750 PRINT#1,"THE YEAR=";A8
2760 PRINT"NUMBER OF FISH CAUGHT DURING"
2770 PRINT"THE YEAR=";A8
2780 PRINT#1:PRINT#1,"CONTINUE?"
2790 PRINT:PRINT"CONTINUE";
2800 GOSUB 3080
2802 PRINT#1," TIME=";T1$
2810 IF R9=1 THEN 2850
2820 IF M6=4 THEN 2890
2830 IF M6=3 THEN 2950
2840 GOTO 2880
2850 LET R=1
2860 LET U1=0
2870 GOTO 1340
2880 IF M6<4 THEN 2950
2890 PRINT#1," DIFFERENT LEVEL OF POLLUTION";
2900 PRINT" DIFFERENT LEVEL OF POLLUTION";
2910 GOSUB 3080
2920 IF R9=1 THEN 2940
2930 GOTO 3030
2940 GOTO 300
2950 IF M6>3 THEN 3030
2960 PRINT#1," DIFFERENT FISHING RATE OR CLOSE SEASON";
2970 PRINT" DIFFERENT FISHING RATE OR CLOSE SEASON";
2980 GOSUB 3080
2990 IF R9=1 THEN 3010
3000 GOTO 3030
3010 LET R=2
3020 GOTO 880
3030 PRINT#1," DO YOU WANT TO START AGAIN";
3040 PRINT"DO YOU WANT TO START AGAIN";
3050 GOSUB 3080
3060 IF R9=0 THEN 3050
3070 R9=0:GOTO 180
3080 INPUT R$:PRINT#1,R$
3090 IF R$="YES" THEN 3140
3100 IF R$="NO" THEN 3160
3110 PRINT#1,"TYPE EITHER YES OR NO"
3120 PRINT"TYPE EITHER YES OR NO"
3130 GOTO 3080
3140 LET R9=1
3150 GOTO 3170
3160 LET R9=0
3170 RETURN
3180 FOR I0=1 TO 5: PRINT#, 1: NEXT: PRINT#: "YEAR " PHYTOPLANKTON×1,000,000,000
3190 PRINT" YEAR " PHYTOPLANKTON×1,000,000,000
3200 PRINT#1, M$: " 0 100 200 300 400
3210 PRINT#1, " 0 100 200 300 400
3220 PRINT#1, " HERBIVORES×1,000,000
3230 PRINT" HERBIVORES×1,000,000
3240 PRINT#1, " 0 20 40 60 80
3250 PRINT" 0 20 40 60 80
3260 IF M6=3 THEN 3300
3270 PRINT#1, " FISH×(ACTUAL NUMBER)
3280 PRINT" FISH×(ACTUAL NUMBER)
3290 GOTO 3340
3300 PRINT#1, " FISH×(ACTUAL NUMBER) FISH
3310 PRINT" FISH×(ACTUAL NUMBER) FISH
3320 PRINT#1, " 0 1000 2000 3000 4000 CAUGHT
3330 PRINT" 0 1000 2000 3000 4000 CAUGHT
3340 PRINT#1, " ++++++++++++++++
3350 PRINT" ++++++++++++++++
3360 RETURN
3370 READ M$
3380 PRINT#1, M$: CHR$(141):
3390 PRINT#1$:
3400 LET P5=P$(.8+.4*RND(0))
3410 LET H5=H$(.8+.4*RND(0))
3420 LET F5=F$(.8+.4*RND(0))
3430 IF ZZ=1 THEN 3480
3440 GOSUB 4140
3450 GOTO 3820
3460 LET P9=INT(P5/2E+10+8.5)
3470 LET H9=INT(H5/4E+06+8.5)
3480 LET F9=INT(F5/200+8.5)
3490 PRINTTAB(8); " : PRINT#1,TAB(8); " : CHR$(141):
3500 IF P9>73 THEN 3540
3510 GOTO 3560
3520 PRINT#1,TAB(70); "P=": INT((P5/1E+09)+.5); CHR$(141):
3530 PRINT"P=": INT((P5/1E+09)+.5); GOTO 3570
3540 GOTO 3580
3550 PRINT"P":TAB(32); "P": PRINT#1,TAB(P9); "P": CHR$(141):
3560 IF P9>H9 THEN 3600
3580 PRINT "J";TAB(H9);"*":PRINT#1,TAB(H9);"*":CHR$(141);
3590 GOTO 3610
3600 PRINT "J";TAB(H9);"H":PRINT#1,TAB(H9);"H":CHR$(141);
3610 IF F9<>P9 THEN 3640
3620 PRINT "J";TAB(F9);"*":PRINT#1,TAB(F9);"*":CHR$(141);
3630 GOTO 3690
3640 IF F9<>H9 THEN 3670
3650 PRINT "J";TAB(F9);"*":PRINT#1,TAB(F9);"*":CHR$(141);
3660 GOTO 3690
3670 PRINT#1,TAB(F9);"F":CHR$(141);
3680 PRINT "J";TAB(F9);"F"
3690 IF M3=0 THEN 3730
3700 PRINT#1,TAB(40);"CLOSE":CHR$(141);
3710 PRINT "J";TAB(30);"CLOSE";
3720 GOTO 3770
3730 LET A7=INT(A7+.5)
3740 IF M6<3 THEN 3770
3750 PRINT#1,TAB(40);A7:CHR$(141);
3760 PRINT "J";TAB(30);A7;
3770 IF M6=3 THEN 3790
3780 PRINT#1;GOTO 3820
3790 LET A8=A8+A7
3800 PRINT#1
3810 PRINT "M"
3820 RETURN
3830 DATA "JAN","FEB","MARCH","APRIL","MAY","JUNE"
3840 DATA "JULY","AUG","SEPT","OCT","NOV","DEC"
3850 PRINT#1
3860 PRINT#1,"END OF PROGRAMME"
3870 PRINT"END OF PROGRAMME"
3880 END
3890 IF AA>0 THEN 3970
3900 PRINT#1,"YEAR":M9
3910 IF M6=3 THEN 3970
3920 PRINT#1,"MONTH PHYTO- HERBI- FISH"
3930 PRINT#1," PLANKTON VORES"
3940 PRINT#1," 9 6"
3950 PRINT#1," (X10) (X10)"
3960 GOTO 4910
3970 PRINT#1,"MONTH PHYTO- HERBI- FISH FISH"
3980 PRINT#1," PLANKTON VORES"
3990 PRINT#1," 9 6"
4000 PRINT#1," CAUGHT"
4000 PRINT#1," (X10 )
4010 IF AA>0 THEN 4090
4020 PRINT"JYEAR";M9
4030 IF M6=3 THEN 4090
4040 PRINT"MONTH PHYTO- HERBI- FISH
4050 PRINT" PLANKTON VOLES"
4060 PRINT" 9 6
4070 PRINT" (X10 ) (X10 )
4080 GOTO 4130
4090 PRINT"MONTH PHYTO- HERBI- FISH FISH
4100 PRINT" PLANKTON VOLES CAUGHT"
4110 PRINT" 9 6
4120 PRINT" (X10 ) (X10 )
4130 RETURN
4140 IF M6=3 THEN 4190
4150 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4160 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5)
4170 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4180 GOTO 4300
4190 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4200 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5)
4210 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4220 IF M3=0 THEN 4260
4230 PRINT#1,TAB(5);"CLOSE"
4240 PRINT TAB(33);"CLOSE"
4250 GOTO 4300
4260 A7=INT(A7+.5)
4270 A8=A8+A7
4280 PRINT#1,TAB(5);A7
4290 PRINTTAB(33);A7
4300 CLOSE2:RETURN
4310 IFR9<1THEN 4440
4311 IFZZ=2THEN4440
4312 PRINT"DEC";TAB(8);":"'
4320 PRINT"J";TAB(P9);"P"
4330 IF P9<H9 THEN 4360
4340 PRINT"J";TAB(H9);"*"
(Appendix 8a)
Appendix 8b

Pedagogic Aims of POND-2

POND-2 simulates a pond where there are three major groups of organisms, or trophic levels, phytoplankton (unicellular green plants such as algae), herbivores and fish. The fish are assumed to be mainly carnivorous and thus feed on the herbivores. When the pond is fished, man becomes a fourth trophic level within the ecosystem.

The phytoplankton are the principal producers (plants such as algae that photosynthesise to produce organic substances) in an aqueous environment. Because the producers are small, the animals that eat them (consumers) also tend to be small. The producers are normally eaten by herbivores (known as primary consumers) which are then eaten by carnivores (secondary consumers). This simple nutritional sequence known as a food chain is used in the POND programs.

In a food chain each organism in the series feeds on, and therefore, derives energy from, the preceding one. It is in turn consumed by, and provides energy for, the one following it. When energy flows through a food chain, only a small proportion of the energy taken up by each link is transferred to the next trophic level because most of the energy is lost as heat through the process of respiration. This progressive loss of energy at each level of a food chain puts a natural limit on the total weight of living matter that can exist at each level. This weight is called the biomass.
The biomass decreases at each successive level in the chain, as does the number of individuals. The decrease in number is greater than that of biomass, because the animals at the end of the chain tend to be larger than their predecessors. The progressive drop in numbers is described as a pyramid of numbers. The progressive drop in biomass is the pyramid of biomass. These two concepts, of a pyramid of numbers and of a pyramid of biomass, are merely two exemplars of the same basic concept, that of a concept of a food pyramid which the POND programs attempt to emphasise.

In mode 1 of the program, the student can observe the behaviour of the pond organisms under "natural" conditions. They can observe the cyclicity of numbers throughout the year and in following years. They can observe the relative sizes of the populations and thus obtain an idea of the pyramid of numbers.

In mode 2 of the program the students can determine the interdependence of the various trophic levels (populations) by experimenting with changing the sizes of the populations at the beginning of year 1, or by removing a whole populations (or populations) from the pond and observing the effect on the remaining populations. They should thus be able to appreciate:

i. That phytoplankton can exist in the absence of any other organism in the pond and thus must be producers their numbers being affected only by the physical environment;

ii. The interrelationship of each population within the pond, i.e. that herbivores eat phytoplankton, and fish eat herbivores.
In mode 3 the student should come to realise that a fourth trophic level has been added to the pond ecosystem, namely man. Man fishes the pond and is thus a predator of the fish. The degree of predation can be varied by changing the fishing rate, that is the number of fishermen and the number of times that they fish each month. In addition, the concept of conservation can be investigated by limiting the amount of fishing by reducing the fishing rate or by imposing a close season at different periods of a year. The optimum fishing rate is two, any fishing rate above this value results in the fish population decreasing in size.

Water can be polluted in many different ways - by heat, detergents, industrial and domestic waste, fertilisers and sewage. The pollution considered by mode 4 of the program is caused by organic compounds in sewage and by mineral salts in fertilisers. In moderate levels the nitrates and phosphates may promote the growth of plants, especially planktonic algae, producing an algal bloom. The bacterial breakdown of both the organic compounds in the sewage and the abundant phytoplankton results in the depletion of oxygen in the water. This is often first noticed when it causes the death of large numbers of fish through oxygen starvation.

Students can investigate the effects of pollution at three different levels - low, medium and high. The polluting material is added during one month of the first year, this month being chosen by the student.
When the fish become extinct they do not reappear in subsequent years as the program makes no provision for re-introduction. Starting the program again restores the populations in each trophic level to their former state.
Appendix 9

Questions used in PONDQU

Mode 1 of Program

Question 1
In a food chain which are the most frequent:
   1) Primary producers (photosynthesisers)?
   2) Consumers?

Question 2
Which are the most frequent in Africa -
   1) Lions,
   2) Zebra,
   3) Plants?
   (** this question is only asked if question 1 or question 3 are answered incorrectly**) 

Question 3

A)  

FISH

HERBIVORES

PHYTOPLANKTON

B)  

FISH

PHYTOPLANKTON

HERBIVORES

C)  

PHYTOPLANKTON

HERBIVORES

FISH

Which pyramid of numbers is correct?
Mode 2 of Program

Question 4a
Have you discovered what happens when there are no phytoplankton, no herbivores, no fish?
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)

Question 4b
Think of the factors that control the numbers of phytoplankton, herbivores and fish.
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)

Question 4c
Why do you think the numbers decrease as you pass from the lowest trophic level to the highest trophic level?
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)

Mode 3 of Program

Question 5
Why have a close season?
Does it conserve fish numbers?

Mode 4 of Program

Question 6a
Have you looked at the effect of a low level of pollution on the plankton?
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)

Question 6b
Why does it kill the fish?
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)

Question 6c
What happens to the phytoplankton?
(***FOLLOWED BY 10 SECONDS THINKING TIME***NO ANSWER REQUIRED)
APPENDIX 10a

LISTING OF PONDQY
10 PRINT"WHAT IS THE TIME";
11 INPUT TI$;
40 OPEN1,4
41 PRINT#1,"TIME=";TI$
50 LET R9=2
80 FOR A=1 TO 5:PRINT#1:NEXT A
90 PRINT#1,"FONDO"
100 PRINT#1,""
110 DIM M$(2),R$(3)
120 GOTO 170
130 PRINT#1,"MODE?"
131 PRINT"MODE";
140 INPUT M$:PRINT#1,M6
150 IF (M6-1)*(M6-2)*(M6-3)*(M6-4)<0 THEN 170
160 GOTO 300
170 PRINT#1,"YOU CAN:-
180 PRINT"J"
180 PRINT"J"
190 PRINT#1,"MODE 1 OBSERVE THE POND"
200 PRINT"MODE 1 OBSERVE THE POND"
210 PRINT#1,"MODE 2 SET INITIAL NUMBERS OF PHYTOPLANKTON,HERBIVORES AND FISH."
220 PRINT"MODE 2 SET INITIAL NUMBERS OF PHYTOPLANKTON,HERBIVORES AND FISH."
230 PRINT#1,"MODE 3 CATCH FISH"
240 PRINT"MODE 3 CATCH FISH"
250 PRINT#1,"MODE 4 POLLUTE THE POND"
260 PRINT"MODE 4 POLLUTE THE POND"
270 PRINT#1,"TYPE 1,2,3 OR 4?"
280 PRINT"TYPE 1,2,3 OR 4?"
290 GOTO 140
300 R=0:U=0:U1=0:M9=0:P=1E+11:H=3.5E+07:F=1000
310 IF M6=4 THEN 350
320 PRINT#1,"DO YOU WANT GRAPHICAL(1) OR TABULAR(2) OUTPUT?"
330 PRINT"DO YOU WANT GRAPHICAL(1) OR TABULAR(2) OUTPUT?"
340 INPUT ZZ:PRINT#1,ZZ: GOTO 360
350 ZZ=2
360 IF M6<>2 THEN 660
370 PRINT#1,"WHAT ARE THE INITIAL NUMBERS OF PHYTOPLANKTON(0-250)x1,000,000,000?"
380 PRINT"WHAT ARE THE INITIAL NUMBERS OF PHYTOPLANKTON(0-250)x1,000,000,000?"
390 PRINT#1," PHYTOPLANKTON(0-250)x1,000,000,000?"
400 PRINT"PHYTOPLANKTON(0-250)x1,000,000,000";
410 INPUT P:PRINT#1,P
420 IF P*(250-P)>0 THEN 460
430 PRINT#1,"***NOT MORE THAN 250 NOR LESS THAN 0?"
440 PRINT#1,"***NOT MORE THAN 250 NOR LESS THAN 0?"
450 GOTO 410
460 LET P=P*1E+09
470 PRINT#1,"HERBIVORES(0-50)*1,000,000?"
480 PRINT"HERBIVORES(0-50)*1,000,000"
490 INPUT H:PRINT#1,H
500 IF H*(50-H)>0 THEN 540
510 PRINT#1,"***NOT MORE THAN 50 NOR LESS THAN 0?"
520 PRINT#1,"***NOT MORE THAN 50 NOR LESS THAN 0?"
530 GOTO 490
540 LET H=H*1E+06
550 PRINT#1," FISH(0-1000)?"
560 PRINT"FISH(0-1000)"
570 INPUT F:PRINT#1,F
580 IF INT(F)=F THEN 620
590 PRINT"***YOU CAN ONLY HAVE COMPLETE FISH?"
600 PRINT#1,"***YOU CAN ONLY HAVE COMPLETE FISH?"
610 GOTO 570
620 IF F*(1000-F)>0 THEN 860
630 PRINT"***NOT MORE THAN 1000 NOR LESS THAN 0"
640 PRINT#1,"***NOT MORE THAN 1000 NOR LESS THAN 0"
650 GOTO 550
660 IF M6<4 THEN 860
670 PRINT#1,"WHAT LEVEL OF POLLUTION"
680 PRINT"WHAT LEVEL OF POLLUTION"
690 PRINT#1,"LOW (1), MODERATE (2) OR HIGH (3)?"
700 PRINT"LOW (1), MODERATE (2) OR HIGH (3)?"
710 INPUT U:PRINT#1,U
720 IF (U-1)*(U-2)*(U-3)=0 THEN 760
730 PRINT#1,"***TYPE 1, 2 OR 3"
740 PRINT"***TYPE 1, 2 OR 3"
750 GOTO 710
760 PRINT#1,"WHEN DOES IT START?"
770 PRINT"WHEN DOES IT START?"
780 INPUT U4:PRINT#1,U4
790 IF U4>INT(U4) THEN 810
800 IF (U4-1)*(12-U4)=0 THEN 840
810 PRINT#1,"***GIVE THE MONTH NUMBER, EG. 3 FOR MARCH"
820 PRINT"***GIVE THE MONTH NUMBER, EG. 3 FOR MARCH"
830 GOTO 780
840 LET U5=U4+1
850 LET U1=1
860 LET A=0
870 LET M4=0
880 LET M5=0
890 IF M6<>3 THEN 1320
900 PRINT#1,"HOW MANY FISHERMEN (0-20)?"
910 PRINT"HOW MANY FISHERMEN (0-20)?"
920 INPUT A:PRINT#1,A
930 IF A=INT(A) THEN 970
940 PRINT#1,"***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
950 PRINT"***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
960 GOTO 900
970 IF A*(20-A)>=0 THEN 1010
980 PRINT#1,"***NOT MORE THAN 20 NOR LESS THAN 0 FISHERMEN"
990 PRINT"***NOT MORE THAN 20 NOR LESS THAN 0 FISHERMEN"
1000 GOTO 900
1010 IF A=0 THEN 1320
1020 PRINT#1,"FISHING FREQUENCY?"
1030 PRINT"FISHING FREQUENCY?"
1040 INPUT A1:PRINT#1,A1
1050 IF (A1-1)*(A1-2)*(A1-3)=0 THEN 1100
1060 PRINT#1,"***YOU CAN FISH 1, 2 OR 4 TIMES A MONTH"
1070 PRINT"***YOU CAN FISH 1, 2 OR 4 TIMES A MONTH"
1080 FOR A1=1 TO 4000: NEXT
1090 GOTO 1040
1100 LET A2=4
1110 IF A1<>2 THEN 1140
1120 LET A2=2
1130 GOTO 1160
1140 IF A1<>4 THEN 1160
1150 LET A2=1
1160 PRINT#1,
1170 PRINT#1,"WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1180 PRINT"WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1190 PRINT#1,"GIVE THE MONTH NUMBER E6.3 FOR MARCH"
1200 PRINT"GIVE THE MONTH NUMBER E6.3 FOR MARCH"
1210 PRINT#1,"FIRST MONTH?"
1220 PRINT"FIRST MONTH?"
1230 INPUT M4:PRINT#1,M4
1240 IF M4=0 THEN 1320
1250 IF M4>INT(M4) THEN 1190
1260 IF (M4-1)*((12-M4)<0) THEN 1190
1270 PRINT#1,"LAST MONTH?"
1280 PRINT"LAST MONTH?"
1290 INPUT M5:PRINT#1,M5
1300 IF M5>INT(M5) THEN 1190
1310 IF (M5-1)*((12-M5)<0) THEN 1190
1320 IF ZZ<1 THEN 310
1330 IF ZZ>2 THEN 310
1340 LET M9=M9+1
1350 IF ZZ=2 THEN 1370
1360 GOTO 1390
1370 GOSUB 3890
1380 GOTO 1400
1390 GOSUB 3180
1400 IF R9=2 THEN 1560
1405 IF R9<1 THEN 1550
1410 IF ZZ=2 THEN 1550
1420 PRINT#1,"DEC";CHR$(141);TAB(8);".";CHR$(141);
1430 PRINT#1,TAB(F9);"P";CHR$(141);
1440 IF F9<>H9 THEN 1470
1450 PRINT#1,TAB(H9);"*";CHR$(141);
1460 GOTO 1480
1470 PRINT#1,TAB(H9);"H";CHR$(141);
1480 IF F9<>P9 THEN 1510
1490 PRINT#1,TAB(F9);"*";CHR$(141);
1500 GOTO 1550
1510 IF F9<>H9 THEN 1540
1520 PRINT#1,TAB(F9);"*";CHR$(141);
1530 GOTO 1550
1540 PRINT#1,TAB(F9);"F"
1550 GOSUB 4310
1560 LET M2=0
1570 LET M=0
1580 LET A8=0
1590 RESTORE
1600 LET I=0
1610 LET A7=0
1620 LET M=M+1
1630 LET M1=0
1640 LET I=I+1
1650 LET M1=M1+7
1660 LET S=SIN(M*28+M1-78)*.0187
1670 IF H>0 THEN 1710
1680 LET H1=0
1690 LET H2=0
1700 GOTO 1870
1710 LET H1=P/H
1720 IF H1>7000 THEN 1760
1730 IF H1<100 THEN 1780
1740 LET H1=4000*(H1-100)/6900
1750 GOTO 1790
1760 LET H1=4000
1770 GOTO 1790
1780 LET H1=0
1790 LET H2=P/1000
1800 IF H2>1E+07 THEN 1840
1810 IF H2<1000 THEN 1860
1820 LET H2=(H2-1000)/9.999E+06
1830 GOTO 1870
1840 LET H2=1
1850 GOTO 1870
1860 LET H2=0
1870 LET H3=H1*H2
1880 LET H4=H3*H
1890 IF F>0 THEN 1920
1900 LET F1=0
1910 GOTO 2020
1920 IF F>.1 THEN-1940
1930 LET F=.1
1940 LET F1=H/F
1950 IF F1>20 THEN 1990
1960 IF F1<20 THEN 2010
1970 LET F1=100*(F1-20)/180
1980 GOTO 2020
2370 LET F8=0
2380 LET F=F6*(1+F8*F1*.003)
2390 IF U=0 THEN 2420
2400 IF (M-U4)*(M-US)<0 THEN 2420
2410 LET F=F/U/1.28
2420 IF F>=1 THEN 2440
2430 LET F=0
2440 LET M3=0
2450 IF A=0 THEN 2660
2460 IF M4<=M5 THEN 2490
2470 IF (M-M4)*(M5-M)<0 THEN 2520
2480 GOTO 2500
2490 IF (M-M4)*(M5-M)<0 THEN 2520
2500 LET M3=1
2510 GOTO 2660
2520 LET M2=M2+1
2530 IF A2<M2 THEN 2660
2540 LET M2=0
2550 IF F>4000 THEN 2590
2560 IF F<50 THEN 2610
2570 LET A3=25*(F-50)/3950
2580 GOTO 2620
2590 LET A3=25
2600 GOTO 2620
2610 LET A3=0
2620 LET A3=A3*2*RND(0)
2630 LET A6=A3*A
2640 LET A7=A7+A6
2650 LET F=F-A6
2660 IF M1<28 THEN 1640
2670 GOSUB 3390
2680 IF I<48 THEN 1610
2690 IF M8<3 THEN 2780
2700 IF A8>0 THEN 2740
2710 PRINT#1, "NO FISH CAUGHT DURING THE YEAR"
2720 PRINT"NO FISH CAUGHT DURING THE YEAR"
2730 GOTO 2780
2740 PRINT#1, "NUMBER OF FISH CAUGHT DURING THE YEAR"
2750 PRINT#1, "THE YEAR=", A8
2760 PRINT"NUMBER OF FISH CAUGHT DURING
2770 PRINT"THE YEAR=":A8
2780 PRINT#1:PRINT#1,"CONTINUE?"
2790 PRINT:PRINT"CONTINUE";
2800 GOSUB 3080
2802 PRINT#1," TIME=";TI$
2810 IF R2=1 THEN 2850
2815 GOSUB5000
2820 IF M6=4 THEN 2890
2830 IF M6=3 THEN 2950
2840 GOTO 2880
2850 LET R=1
2860 LET U1=0
2870 GOTO 1340
2880 IF M6<4 THEN 2950
2890 PRINT#1." DIFFERENT LEVEL OF POLLUTION"
2900 PRINT" DIFFERENT LEVEL OF POLLUTION"
2910 GOSUB 3080
2920 IF R9=1 THEN 2940
2930 GOTO 3030
2940 GOTO 3000
2950 IF M6<3 THEN 3030
2960 PRINT#1." DIFFERENT FISHING RATE OR CLOSE SEASON"
2970 PRINT" DIFFERENT FISHING RATE OR CLOSE SEASON"
2980 GOSUB 3080
2990 IF R9=1 THEN 3010
3000 GOTO 3030
3010 LET R=2
3020 GOTO 880
3030 PRINT#1." DO YOU WANT TO START AGAIN"
3040 PRINT" DO YOU WANT TO START AGAIN"
3050 GOSUB 3080
3060 IF R9=0 THEN 3050
3070 R9=0:GOTO 180
3080 INPUT R$;PRINT#1,R$
3090 IF R$="YES" THEN 3140
3100 IF R$="NO" THEN 3160
3110 PRINT#1,"TYPE EITHER YES OR NO"
3120 PRINT" TYPE EITHER YES OR NO"
3130 GOTO 3080
3140 LET R9=1
3150 GOTO 3170
3160 LET R9=0
3170 RETURN
3180 FORI=1TO5:PRINT#1:NEXT:PRINT#1,"YEAR ":PRINT#1:PHOTOPLANKTON"X 1,000,000,000"
3190 PRINT"YEAR ":PRINT#1:PHOTOPLANKTON"X 1,000,000,000"
3200 PRINT#1,M9:" 0 100 200 300 400
3210 PRINTM9:" 0 100 200 300 400
3220 PRINT#1," HERBIVORES"X 1000,000"
3230 PRINT" HERBIVORES"X 1000,000"
3240 PRINT#1," 0 20 40 60 80
3250 PRINT" 0 20 40 60 80
3260 IF M6=3 THEN 3300
3270 PRINT#1," FISH (ACTUAL NUMBER)"
3280 PRINT" FISH (ACTUAL NUMBER)"
3290 GOTO 3340
3300 PRINT#1," FISH (ACTUAL NUMBER) FISH"
3310 PRINT" FISH (ACTUAL NUMBER)"
3320 PRINT#1," 0 1000 2000 3000 4000 CAUGHT"
3330 PRINT" 0 1000 2000 3000 4000 CAUGHT"
3340 PRINT#1," ++++++++++++++++
3350 PRINT" ++++++++++++++++"
3360 PRINT#1," ++++++++++++++++
3370 PRINT" ++++++++++++++++"
3380 RETURN
3390 READ M$
3400 PRINT#1,M$:CHR$(141)
3410 PRINTM$
3420 LET P5=P*(.8+.4*RND(0))
3430 LET H5=H*(.8+.4*RND(0))
3440 LET F5=F*(.9+.2*RND(0))
3450 IF ZZ=1 THEN 3480
3460 GOSUB 4140
3470 GOTO 3820
3480 LET P9=INT(P5/2E+10+.5)
3490 LET H9=INT(H5/4E+10+.5)
3500 LET F9=INT(F5/200+8.5)
3510 PRINTTAB(8);",";PRINT#1,TAB(8);",";CHR$(141)
3520 IF P9>79 THEN 3540
3530 GOTO 3560
3540 PRINT#1,TAB(70);"P=";INT((P5/1E+09)+.5);CHR$(141)
3550 PRINT"P=";INT((P5/1E+09)+.5);GOTO 3570
3560 PRINT"P=";TAB(P9);"P"; PRINT#1,TAB(P9);"P";CHR$(141)
3570 IF F9<>H9 THEN 3600
3580 PRINT"J";TAB(H9);"*:PRINT#1,TAB(H9);"*";CHR$(141);
3590 GOTO 3610
3600 PRINT"J";TAB(H9);"H":PRINT#1,TAB(H9);"H":CHR$(141);
3610 IF F9<>F9 THEN 3640
3620 PRINT"J";TAB(F9);"*:PRINT#1,TAB(F9);"*";CHR$(141);
3630 GOTO 3690
3640 IF F9<>H9 THEN 3670
3650 PRINT"J";TAB(F9);"*:PRINT#1,TAB(F9);"*";CHR$(141);
3660 GOTO 3690
3670 PRINT#1,TAB(F9);"F":CHR$(141);
3680 PRINT"J";TAB(F9);"F"
3690 IF M3=0 THEN 3730
3700 PRINT#1,TAB(40);"CLOSE":CHR$(141);
3710 PRINT"J";TAB(30);"CLOSE";
3720 GOTO 3770
3730 LET A7=INT(A7+.5)
3740 IF M6<>3 THEN 3770
3750 PRINT#1,TAB(40);A7;CHR$(141);
3760 PRINT"J";TAB(30);A7;
3770 IF M6=3 THEN 3790
3780 PRINT#1:GOTO 3820
3790 LET AB=AB+A7
3800 PRINT#1
3810 PRINT"IM"
3820 RETURN
3830 DATA "JAN","FEB","MARCH","APRIL","MAY","JUNE"
3840 DATA "JULY","AUG","SEPT","OCT","NOV","DEC"
3850 PRINT#1
3860 PRINT#1,"END OF PROGRAMME"
3870 PRINT"END OF PROGRAMME"
3880 END
3890 IF AA>0 THEN 3970
3900 PRINT#1,"YEAR";M9
3910 IF M6=3 THEN 3970
3920 PRINT#1,"MONTH PHOTOPHERBI- FISH"
3930 PRINT#1," PLANKTON YORES"
3940 PRINT#1," 9 6"
3950 PRINT#1," (X10 ) (X10 )"
3960 GOTO 4010
3370 PRINT#1,"MONTH PHYTO-" HERBI- FISH FISH FISH
3380 PRINT#1," PLANKTON VORES CAUGHT  "
3390 PRINT#1," 3 5
4000 PRINT#1,"(X10 )" (X10 )
4010 IF AA>0 THEN 4090
4020 PRINT"\YEAR":M2
4030 IF M6=3 THEN 4090
4040 PRINT"MONTH PHYTO-" HERBI- FISH
4050 PRINT" PLANKTON VORES"
4060 PRINT" 9 6"
4070 PRINT"(X10 )" (X10 )
4080 GOTO 4130
4090 PRINT"MONTH PHYTO-" HERBI- FISH FISH
4100 PRINT" PLANKTON VORES"
4110 PRINT" 9 6"
4120 PRINT"(X10 )" (X10 )
4130 RETURN
4140 IF M6=3 THEN 4190
4150 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4160 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5)
4170 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4180 GOTO 4300
4190 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4200 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5)
4210 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4220 IF M3=0 THEN 4260
4230 PRINT#1,TAB(5);"CLOSE"
4240 PRINT TAB(33);"CLOSE"
4250 GOTO 4300
4260 A7=INT(A7+.5)
4270 A8=A8+A7
4280 PRINT#1,TAB(5);A7
4290 PRINTTAB(33);A7
4300 CLOSE2:RETURN
4310 IFR9<1THEN 4440
4311 IFZZ=2THEN4440
4312 PRINT"DEC";TAB(8);".""
4320 PRINT"T";TAB(P9);"P"
4330 IF P9>H9 THEN 4360
4340 PRINT"T";TAB(H9);"*"

(appendix 10a)
4350 GOTO 4370
4360 PRINT"J";TAB(H9);"H"
4370 IF F9<F9 THEN 4400
4380 PRINT"J";TAB(F9);"*
4390 GOTO 4440
4400 IF F9>F9 THEN 4430
4410 PRINT"J";TAB(F9);"*
4420 GOTO 4440
4430 PRINT"J";TAB(F9);"F"
4440 RETURN
5000 IF MW1=0 THEN 5020
5001 IF MW1=2 THEN 5000
5002 IF MW1=3 THEN 7000
5003 GOTO 5000
5010 MW1=0 THEN 9000
5025 RW=RW+1
5030 FOR II=1 TO 3:PRINT#1:NEXT II
5035 PRINT"A FOOD CHAIN WHICH ARE THE MOST FREQUENT:
5036 PRINT"A PRIMARY PRODUCERS(PHOTOSYNTHESISERS)?
5037 PRINT"A PRIMARY PRODUCERS(PHOTOSYNTHESISERS)?
5038 PRINT"A CONSUMERS(PREDATORS)?
5039 PRINT"A OR 2"
5040 INPUT#1,AB
5045 IF AB<1 THEN 5200
5050 FOR II=1 TO 3:PRINT#1:NEXT II
5055 PRINT"A"
5060 PRINT"A HERBIVORES
5065 PRINT"A PHYTOPLANKTON
5070 PRINT"A FISH
5075 PRINT"A FISH
5080 PRINT"A HERBIVORES
5085 PRINT"A FISH
5090 PRINT"A PHYTOPLANKTON
5095 PRINT"A FISH
5100 PRINT"A PHYTOPLANKTON
5105 PRINT"A HERBIVORES
5110 PRINT"A FISH
5115 PRINT"A PHYTOPLANKTON
5120 PRINT"A FISH
5125 PRINT"A PHYTOPLANKTON
5130 PRINT"A HERBIVORES
5135 PRINT"A FISH
5140 PRINT"A PHYTOPLANKTON
5145 PRINT"A FISH
5150 PRINT"A PHYTOPLANKTON
5155 PRINT"A HERBIVORES
5160 PRINT"A FISH
5165 PRINT"A PHYTOPLANKTON
5170 PRINT"A FISH
5175 PRINT"A PHYTOPLANKTON
5180 PRINT"A HERBIVORES
5185 PRINT"A FISH
5190 PRINT"A PHYTOPLANKTON
5195 PRINT"A FISH
5200 RETURN
()}
5087 PRINT#1,",HERBIVORES
5088 PRINT#1,",PHYTOPLANKTON
5089 PRINT "HERBIVORES
5090 PRINT "PHYTOPLANKTON
5091 PRINT#1,"A"
5092 PRINT#1,"B"
5093 PRINT#1,"C"
5094 PRINT#1,"D"
5095 PRINT#1,"E"
5096 PRINT#1,"F"
5097 PRINT#1,"G"
5098 PRINT#1,"H"
5099 PRINT:PRINT"WHICH PYRAMID OF NUMBERS IS CORRECT";
5100 PRINT#1:PRINT#1,"WHICH PYRAMID OF NUMBERS IS CORRECT?";
5101 INPUTY$:PRINT#1,TY$
5102 IFTY$="A"THEN9999
5200 PRINT"WHICH ARE THE MOST FREQUENT IN AFRICA- 1>LIONS,2>ZEBA,3>PLANTS";
5201 PRINT#1,"WHICH ARE THE MOST FREQUENT IN AFRICA-
5202 PRINT#1,"1>LIONS,2>ZEBA,3>PLANTS?";
5225 INPUTJJ:PRINT#1,JJ
5230 IF JJ=3THEN5072
5235 PRINT"DON'T BE STUPID, THINK CAREFULLY"
5236 PRINT#1,"DON'T BE STUPID, THINK CAREFULLY"
5237 GOTO 5200
6000 RX=RX+1:IFRX>2THEN9999:PRINT#1:PRINT#1:PRINT#1
6005 IFRX=2THEN6100
6010 PRINT"HAVE YOU DISCOVERED WHAT HAPPENS WHEN
6011 PRINT#1,"HAVE YOU DISCOVERED WHAT HAPPENS WHEN
6015 PRINT"THERE ARE NO PHYTOPLANKTON,NO HERBIVORES,NO FISH?"
6016 PRINT#1,"THERE ARE NO PHYTOPLANKTON,NO HERBIVORES,NO FISH?"
6027 PRINT#1:PRINT#1
6100 PRINT"THINK OF THE FACTORS THAT CONTROL THE
6101 PRINT#1,"THINK OF THE FACTORS THAT CONTROL THE
6105 PRINT"NUMBERS OF PHYTOPLANKTON,HERBIVORES AND FISH
6106 PRINT#1,"NUMBERS OF PHYTOPLANKTON,HERBIVORES AND FISH
6107 PRINT#1:PRINT#1
6110 FORAS=1TO10000:NEXTAS
6115 PRINT"WHY DO YOU THINK THE NUMBERS DECREASE AS";
6116 PRINT#1,"WHY DO YOU THINK THE NUMBERS DECREASE AS"
6120 PRINT"YOU PASS FROM THE LOWEST TROPHIC LEVEL
6121 PRINT#1,"YOU PASS FROM THE LOWEST TROPHIC LEVEL
6125 PRINT"TO THE HIGHEST TROPHIC LEVEL?
6126 PRINT#1,"TO THE HIGHEST TROPHIC LEVEL?
6130 FOR AS=1TO10000:NEXTAS
6135 GOTO8999
7000 AD=AD+1
7005 PRINT"WHY HAVE CLOSE SEASON?"
7006 PRINT#1,"WHY HAVE CLOSE SEASON?"
7010 PRINT"DOES IT CONSERVE FISH NUMBERS?"
7015 GOSUB3080
7020 IF R9=1 THEN8999
7025 PRINT"THINK AGAIN"
7026 PRINT#1,"THINK AGAIN"
7030 GOTO7015
8000 PRINT"HAVE YOU LOOKED AT THE EFFECT OF A"
8001 PRINT#1,"HAVE YOU LOOKED AT THE EFFECT OF A"
8005 PRINT"LOW LEVEL OF POLLUTION ON THE PLANKTON?"
8006 PRINT#1,"LOW LEVEL OF POLLUTION ON THE PLANKTON?"
8007 PRINT"WHY DOES IT KILL THE FISH?"
8008 PRINT#1,"WHY DOES IT KILL THE FISH?"
8009 PRINT"WHAT HAPPENS TO THE PHYTOPLANKTON?"
8010 PRINT#1,"WHAT HAPPENS TO THE PHYTOPLANKTON?"
8011 FOR DF=1 TO10000:NEXT DF
8999 PRINT"GOOD NOW CARRY ON":PRINT#1,"GOOD NOW CARRY ON"
9000 RETURN
Appendix 10b

Pedagogic Aims of PONDQU

Mode 1, that is observation of the pond, should enable students to observe the relative frequencies of the different organisms and the cyclical changes in the size of the three populations. Following the use of this program, the student is asked whether the primary consumers (photosynthetic algae) or the consumers are most frequent in the ecosystem. This should cause the student to think of the organisms in the pond (phytoplankton, herbivores and fish) and their role in the pond ecosystem. The phytoplankton should be regarded as being plants, and as such are photosynthetic producing food from the carbon dioxide dissolved in the water from the atmosphere using sunlight as a source of energy for the process. The phytoplankton are utilised as a source of food by the herbivorous animals who are the primary consumers in the pond. These herbivores are utilised, in turn, by the least frequent of the populations, the secondary consumers which are carnivorous fish.

The questioning progresses to the food pyramid concept, diagrams of the food pyramid being drawn to direct the student to realise that there are more herbivores than fish, and more phytoplankton than herbivores. The student is asked to choose the correct pyramid from a set of three pyramids drawn on the screen. If the correct answer is provided, the student is allowed to progress to the next mode that he or she wishes to use. If, however, the incorrect response is given to the question, then the program is routed to provide another question related to the pyramid of numbers. In this question, a well-known example of a food chain is given (grass, zebra and lion) which corresponds to the primary producers, primary consumers and secondary consumers respectively.
The student is asked which of these organisms is the most common in Africa, the correct answer, of course, being grass. Once the student achieves the correct answer, and there should be no difficulty here, the program is routed back to the pyramid of numbers question previously presented. Hopefully, the student can now answer that question with a little thought.

Following the use of mode 2 of the program where the student can alter the initial numbers of the three types of organism found in the pond to see the effect of having different numbers of each of the organism, the students are asked whether they have discovered what happens to the pond ecology if each of the organisms, in turn, are omitted from the pond. In this way, it is hoped that if the student has not discovered the purpose of each of the organisms, or role of each of the organisms in the pond, the s/he will go back to this mode and discover each of their roles.

In addition, the students are asked to think of the factors that control the numbers of each of the different organisms. For example, that the amount of light will affect the number of phytoplankton, also the amount of predation by herbivores. A third question is asked of the students. This question is "Why do you think the numbers decrease as you pass from the lowest trophic level to the highest trophic level?". In addition to asking the students to think of an explanation which might be used in this situation, the question also introduces the concept "trophic level". In the question, the students are told that the lowest trophic level has the greatest number of organisms, and that as one progresses from this trophic level to the highest trophic level, the number of organisms decreases. Knowing
this, and that the phytoplankton are the most frequent organisms in the pond, one can deduce that the phytoplankton form the lowest trophic level in the ecosystem, the herbivores the middle trophic level, and the fish, the least frequent organisms in the pond, the highest trophic level.

In mode 3 the pond can be fished at different frequencies and rates and the effect that this has on the pond ecology can be determined. Following the use of this mode there is a simple YES/NO question appertaining to the purpose of the close season for fishing. This is the only question asked in this mode of the program.

Following mode 4 of the program, pollution of the pond at three different levels, the questions ask the student whether s/he has tried a low level of pollution (since this does not kill the phytoplankton but causes a rapid increase in their numbers forming an algal bloom). The student is asked to think why the pollutant kills the fish and what happens to the phytoplankton at the low level of pollution. This latter question should encourage the students to observe the vast increase in phytoplankton numbers if s/he has not already done so.
With each of the questions in modes 2 and 4 which merely require the student to think about a particular point and not provide an answer to the computer, ten seconds of thinking time is given for each of the questions. This compels the students to at least look at the question for that period of time. It will hopefully cause some direction of their thoughts towards these important points of the program. The alternative would be to ask the question and then go on directly to the next question. This would probably result in the student not even reading the question and directing their thoughts towards these points.
APPENDIX 11

LISTING OF PONDGAME
1 OPEN 1,4
2 PRINT"WHAT IS THE TIME"; INPUT$; PRINT#1,":TIME="; TI$
3 GOSUB 5000
4 R=0: U=0: M9=0: D=0: C=0: C1=0: B=0: A=0: A1=0
5 PRINT"DO YOU WANT YOUR RESULTS IN (1)GRAPHICAL OR (2)TABULAR FORM?"
6 PRINT"TYPE 1 OR 2":
7 PRINT#1,"DO YOU WANT YOUR RESULTS IN (1)GRAPHICAL OR (2)TABULAR FORM?"
8 PRINT#1, "TYPE 1 OR 2?"; PRINT#1, ZZ
9 PRINT"WHAT NUMBER OF PHYTOPLANKTON DO YOU WANT TO START WITH IN THE POND?"
10 PRINT"YOU CAN HAVE 0-250(X 10^3X0)";
11 PRINT#1,"WHAT NO. OF PHYTOPLANKTON DO YOU WANT TO START WITH IN THE POND?"
12 PRINT#1,"YOU CAN HAVE 0-250(X 10^3X0)"; INPUTP; PRINT#1,P
13 IF P<(50-P) THEN 160
14 PRINT"***NOT MORE THAN 250 NOR LESS THAN 0"
15 PRINT#1,"***NOT MORE THAN 250 NOR LESS THAN 0": GOTO 112
16 LET P=P*1E+09
17 PRINT"WHAT NUMBER OF HERBIVORES DO YOU WANT TO START WITH IN THE POND?"
18 PRINT"YOU CAN HAVE 0-50(X 10^3X0)";
19 PRINT#1,"WHAT NUMBER OF HERBIVORES DO YOU WANT TO START WITH IN THE POND?"
20 PRINT#1,"YOU CAN HAVE 0-50(X 10^3X0)"; INPUTH; PRINT#1,H
21 IF H<(50-H) THEN 199
22 PRINT"***NOT MORE THAN 50 NOR LESS THAN 0"
23 PRINT#1,"***NOT MORE THAN 50 NOR LESS THAN 0"
24 GOTO 174
25 H=H*1E+06
26 PRINT"WHAT NUMBER OF FISH DO YOU WANT TO START WITH IN THE POND?"
27 PRINT"YOU CAN HAVE 0-1000";
28 PRINT#1,"WHAT NUMBER OF FISH DO YOU WANT TO START WITH IN THE POND?"
29 PRINT#1,"YOU CAN HAVE 0-1000"; INPUT F; PRINT#1,F
30 IF INT(F)=F THEN 215
31 PRINT"***YOU CAN ONLY HAVE COMPLETE FISH"
32 PRINT#1,"***YOU CAN ONLY HAVE COMPLETE FISH"
33 GOTO 210
34 IF F<(1000-F) THEN 500
35 PRINT"***NOT MORE THAN 1000 NOR LESS THAN 0"
36 PRINT#1,"***NOT MORE THAN 1000 NOR LESS THAN 0"
37 GOTO 203
38 500 PRINT"DO YOU WANT TO REMOVE FISH FROM YOUR
39 501 PRINT#1,"DO YOU WANT TO REMOVE FISH FROM YOUR
510 PRINT"POND FOR SALE TO THE PUBLIC";
511 PRINT#1,"POND FOR SALE TO THE PUBLIC?";
520 GOSUB3080
530 IFR9=0 THEN1031
531 IFR9=1 THEN535
532 YY=0: GOTO1031
535 YY=1
540 PRINT"WHAT % OF YOUR FISH STOCK WILL YOU SELL EACH WEEK";
541 PRINT#1,"WHAT % OF YOUR FISH STOCK WILL YOU SELL EACH WEEK";
560 INPUTB: PRINT#1, B
561 IF B>100 THEN 563
562 IF B<=0 THEN 1031
563 PRINT"***NOT MORE THAN 100% NOR LESS THAN 0%"
564 PRINT#1,"***NOT MORE THAN 100% NOR LESS THAN 0%"
565 GOTO 0560
1031 PRINT:"DO YOU WISH TO FISH THE POND";
1032 PRINT#1,"DO YOU WISH TO FISH THE POND?"; GOSUB3080
1033 IF R9=0 THEN 1400
1034 PRINT"HOW MANY FISHERMEN(0-20)"
1035 PRINT#1,"HOW MANY FISHERMEN(0-20)?"; INPUTA: PRINT#1, A
1036 MS=3
1037 IF A=INT(A) THEN 1041
1038 PRINT"***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
1039 PRINT#1,"***YOU CAN ONLY HAVE COMPLETE FISHERMEN"
1040 GOTO 1034
1041 IF (20-A)>=0 THEN 1045
1042 PRINT"***NOT MORE THAN 20 NOR LESS THAN 0"
1043 PRINT#1,"***NOT MORE THAN 20 NOR LESS THAN 0"
1044 GOTO 1034
1045 IF A=0 THEN 1400
1141 PRINT"HOW MANY TIMES A MONTH DO THE FISHERMEN FISH YOUR POND?"
1142 PRINT"THEY CAN FISH 1,2 OR 4 TIMES A MONTH";
1143 PRINT#1,"HOW MANY TIMES A MONTH DO THE FISHERMEN FISH YOUR POND?"
1144 PRINT#1,"THEY CAN FISH 1,2 OR 4 TIMES A MONTH?"
1150 INPUT A1: PRINT#1, A1
1151 IF (A1-1)*(A1-2)*(A1-4)=0 THEN 1190
1152 PRINT"***YOU CAN FISH 1,2 OR 4 TIMES/MONTH"
1153 PRINT#1,"***YOU CAN FISH 1,2 OR 4 TIMES EACH MONTH"
1154 GOTO 1150
1190 A2=4
1200 IFA1<2 THEN 1230
1210 LET A2=2
1220 GOTO 1251
1230 IFA1<4 THEN 1251
1240 A2=1
1251 PRINT"WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1252 PRINT#1,"WHAT ARE THE MONTHS OF THE CLOSE SEASON?"
1260 PRINT"GIVE THE MONTH NUMBER, EG 3 FOR MARCH"
1261 PRINT#1,"GIVE THE MONTH NUMBER, EG 3 FOR MARCH"
1270 PRINT"IF YOU DO NOT WANT TO HAVE A CLOSE SEASON THEN TYPE '0'."
1271 PRINT#1,"IF YOU DO NOT WANT TO HAVE A CLOSE SEASON THEN TYPE '0'."
1280 PRINT"FIRST MONTH";
1281 PRINT#1," FIRST MONTH?";
1290 INPUT M4:PRINT#1, M4
1300 IF M4=0 THEN 1400
1301 IF M4>INT(M4) THEN 1260
1302 IF (M4-1)*(12-M4)<0 THEN 1260
1330 PRINT"LAST MONTH";
1331 PRINT#1," LAST MONTH?";
1340 INPUT M5:PRINT#1, M5
1341 IF M5>INT(M5) THEN 1260
1342 IF (M5-1)*(12-M5)<0 THEN 1260
1400 REM
1401 PRINT"IS YOUR POND BEING POLLUTED?";
1402 PRINT#1,"IS YOUR POND BEING POLLUTED?";
1410 GOSUB 3080
1420 IFR3=0 THEN 1500
1421 IF ZZ=2 THEN 1430
1422 PRINT"I AM CHANGING YOUR GRAPHICAL OUTPUT TO TABULAR"
1424 PRINT#1,"I AM CHANGING YOUR GRAPHICAL OUTPUT TO TABULAR"
1426 PRINT#1,"THIS WILL BE EASIER FOR YOU TO SEE WHAT IS HAPPENING."
1427 PRINT#1,"THIS WILL BE EASIER FOR YOU TO SEE WHAT IS HAPPENING."
1428 ZZ=2
1430 PRINT"WHAT LEVEL OF POLLUTION DO YOU WANT?"
1431 PRINT#1,"WHAT LEVEL OF POLLUTION DO YOU WANT?"
1440 PRINT"LOW(1), MODERATE(2), OR HIGH(3)?";
1441 PRINT#1,"LOW(1), MODERATE(2), OR HIGH(3)??";
1450 INPUT U:T6=4:PRINT#1,U
1451 IF(U-1)*(U-2)*(U-3)=0THEN1490
1452 PRINT"***TYPE 1,2 OR 3"
1453 PRINT#1,"***TYPE 1,2 OR 3"
1454 GOTO1450
1490 PRINT"WHEN DOES IT OCCUR"
1491 PRINT"GIVE THE MONTH NUMBER, EG. 3 FOR MARCH"
1492 PRINT#1,"WHEN DOES IT OCCUR"
1493 PRINT#1,"GIVE THE MONTH NUMBER, EG. 3 FOR MARCH?"
1494 INPUTU4:PRINT#1,U4
1495 IFU4>INT(U4)THEN1497
1496 IF(U4-1)*(12-U4)=0THEN1499
1497 GOTO1490
1499 U5=U4+1:U1=1
1500 LETM9=M9+1
1501 IFZ2=2THEN1505
1502 GOSUB3180
1503 GOTO1560
1505 GOSUB3890
1560 LET M2=0
1570 LET M=0
1580 LET A8=0
1590 RESTORE
1600 LET I=0
1610 LET A7=0
1620 LET M=M+1
1630 LET M1=0
1640 LET I=I+1
1650 LET M1=M1+7
1660 LET S=SIN((M*28+M1-78)*.0187)
1670 IF H>0 THEN 1710
1680 LET H1=0
1690 LET H2=0
1700 GOTO1870
1710 LET H1=P/H
1720 IF H1>7000 THEN 1760
1730 IF H1<100 THEN 1780
1740 LET H1=4000*(H1-100)/6900
1750 GOTO1790
1760 LET H1=4000
1770 GOTO1790
1780 LET H1=0
1790 LET H2=P/1000
1800 IF H2>1E+07 THEN 1840
1810 IF H2<1000 THEN 1860
1820 LET H2=(H2-1000)/0.999E+06
1830 GOTO 1870
1840 LET H2=1
1850 GOTO 1870
1860 LET H2=0
1870 LET H3=H1*H2
1880 LET H4=H1*H2
1890 IF F>0 THEN 1920
1900 LET F1=0
1910 GOTO 2020
1920 IF F>1 THEN 1940
1930 LET F=.1
1940 LET F1=H/F
1950 IF F1>200 THEN 1990
1960 IF F1<20 THEN 2010
1970 LET F1=100*(F1-20)/100
1980 GOTO 2020
1990 LET F1=100
2000 GOTO 2020
2010 LET F1=0
2020 LET S1=S*1E+10+1.4E+11
2030 LET S2=S+4
2040 LET P1=(P-H4/1.8)*.45
2050 IF (P+P1)/2=C=S1 THEN 2100
2060 LET P2=(P+P1)/2-S1
2070 LET S2=S2-(S2-1)*P2/S1
2080 IF S2>1 THEN 2100
2090 LET S2=1
2100 LET P=P1*S2
2110 IF U1=0 THEN 2170
2120 IF (M-U4)*(M-U5)<0 THEN 2170
2130 IF U=3 THEN 2160
2140 LET P=P*4
2150 GOTO 2170
2160 LET P=P/4
2170 IF P>0 THEN 2190
2180 LET F=0
2190 LET H=(H-F*F1%20)*(H1*.000045+.8)*(H3*.00005+1)
2200 IF U1=0 THEN 2240
2210 IF U=1 THEN 2240
2220 IF (M-U4)%(M-U5)<0 THEN 2240
2230 LET H=H/2
2240 IF H>0 THEN 2260
2250 LET H=0
2260 LET F7=.97
2270 IF (M-4)%(10-M)<0 THEN 2290
2280 LET F7=F7-F1*.00017
2290 LET F6=F6+F7
2300 IF (M-4)%(M-5)<0 THEN 2370
2310 IF F<3000 THEN 2350
2320 IF F>4000 THEN 2370
2330 LET F8=1-(F-3000)/1000
2340 GOTO 2360
2350 LET F8=1
2360 GOTO 2360
2370 LET F8=0
2380 LET F=F6*(1+F8*F1*.003)
2381 IF Y>0 THEN 2390
2382 XX=F*B/100:F=F-XX
2383 I=I+XX
2390 IF U=0 THEN 2420
2400 IF (M-U4)%(M-U5)<0 THEN 2420
2410 LET F=F/U/1.28
2420 IF F=1 THEN 2440
2430 LET F=0
2440 LET M3=0
2450 IF A=0 THEN 2660
2460 IF M4=M5 THEN 2490
2470 IF (M-M4)%(M5-M)<0 THEN 2520
2480 GOTO 2500
2490 IF (M-M4)%(M5-M)<0 THEN 2520
2500 LET M3=1
2510 GOTO 2660
2520 LET M2=M2+1
2530 IF A2>M2 THEN 2660
2540 LET M2=0
2550 IF F>4000 THEN 2590
2560 IF F<50 THEN 2610
2570 LET A3=25*(F-50)/3950
2580 GOTO 2620
2590 LET A3=25
2600 GOTO 2620
2610 LET A3=0
2620 LET A3=A3*2*RND(0)
2630 LET A6=A3*A
2640 LET A7=A7+A6
2650 LET F=F-A6
2660 IF M1<28 THEN 1640
2670 GOSUB 3390
2680 IF I<48 THEN 1610
2690 IF M6<3 THEN 2771
2700 IF A8>0 THEN 2740
2710 PRINT#1, "NO FISH CAUGHT DURING THE YEAR"
2720 PRINT "NO FISH CAUGHT DURING THE YEAR"
2721 PRINT "FISHING NO GOOD.WILL NOT FISH HERE AGAIN";
2722 PRINT#1,"FISHING NO GOOD.WILL NOT FISH HERE AGAIN"
2730 M6=0:GOTO 2771
2740 PRINT#1,"NUMBER OF FISH CAUGHT DURING YEAR=","A8
2750 IF A8<(A1*A1)>4THEN2750
2752 PRINT "NO FISH CAUGHT DURING THE YEAR"
2753 PRINT "FISHING NO GOOD.WILL NOT FISH HERE AGAIN"
2760 PRINT "NUMBER OF FISH CAUGHT DURING YEAR=","A8
2770 PRINT "NUMBER OF FISH SOLD=",INT(D+.5)
2771 C=(120*A*A1)+(D*3)-1000:C1=C1+C:IFM6=3THEN2775
2774 A=0:A1=0
2775 PRINT "PROFIT/LOSS FOR YEAR= ";INT(C+.5)
2776 PRINT "TOTAL PROFIT/LOSS = ";INT(C1+.5)
2777 PRINT#1,"NUMBER OF FISH SOLD=",INT(D+.5)
2778 PRINT#1,"PROFIT/LOSS FOR YEAR= ";INT(C+.5)
2779 PRINT#1,"TOTAL PROFIT/LOSS = ";INT(C1+.5)
2780 PRINT#1:PRINT#1,"CONTINUE?"
2790 PRINT "CONTINUE";
2800 GOSUB 3050
2802 PRINT#1,""
2810 IF R9=1 THEN 2850
2840 GOTO 2871
2850 LET R1=0:C=0:D=0:00=0
2860 LET U1=0
2870 GOTO 1500
2871 PRINT"DO YOU WANT TO CONTINUE BUT CHANGING ONE OF THE FOLLOWING:
2872 PRINT"DO YOU WANT TO CONTINUE BUT CHANGING ONE OF THE FOLLOWING:
2873 PRINT"RESULTS OUTPUT(GRAPH,TABLE)
2874 PRINT"RESULTS OUTPUT(GRAPH,TABLE)
2875 PRINT"PERCENTAGE FISH HARVESTED/WEEK?
2876 PRINT"PERCENTAGE FISH HARVESTED/WEEK?
2877 PRINT"NO. OF FISHERMEN?
2878 PRINT"NO. OF FISHERMEN?
2879 PRINT"FISHING FREQUENCY?
2880 PRINT"FISHING FREQUENCY?
2881 PRINT"CLOSE SEASON?
2882 PRINT"WHICH DO YOU WANT TO VARY?":00=1
2883 PRINT"WHICH DO YOU WANT TO VARY?":00=1
2884 PRINT"WHICH DO YOU WANT TO VARY?":00=1
2885 IFR9=THEN3030
2886 PRINT"WHICH DO YOU WANT TO VARY?":00=1
2887 INPUTVY:PRINT#1,VY
2888 IFVY<1THEN2894
2889 PRINT"GRAPH(TYPE 1),TABLE(TYPE 2)"
2890 PRINT"GRAPH(TYPE 1),TABLE(TYPE 2)"
2891 GOTO3011
2892 GOTO3011
2893 IFVY<2THEN2898
2894 IFVY<2THEN2898
2895 PRINT"WHAT PERCENTAGE OF YOUR FISH DO YOU WANT TO HARVEST EACH WEEK?"
2896 PRINT"WHAT PERCENTAGE OF YOUR FISH DO YOU WANT TO HARVEST EACH WEEK?"
2897 VY=1:INPUTVY:PRINT#1,B:GOTO3011
2898 IFVY<3THEN2985
2899 PRINT"HOW MANY FISHERMEN<0-20)"
2900 PRINT"HOW MANY FISHERMEN<0-20)"
2901 IFA=0THEN3011
2902 IFA=0THEN3011
2903 GOTO3011
2904 IFVY<4THEN2996
2905 IFVY<4THEN2996
2906 PRINT"WHAT IS THE FISHING FREQUENCY (1, 2 OR 4 TIMES EACH MONTH)"
2907 PRINT"WHAT IS THE FISHING FREQUENCY (1, 2 OR 4 TIMES EACH MONTH)"
2908 INPUTAI:PRINT#1,A1:M6=3
2909 INPUTAI:PRINT#1,A1:M6=3
2989 A2=4
2990 IFAI<>2THEN2993
2991 A2=2
2992 REM
2993 IFAI<>2THEN2995
2994 A2=1
2995 GOTO3001
2996 PRINT"WHAT IS THE CLOSE SEASON?":PRINT#1,"WHAT IS THE CLOSE SEASON?";
3000 PRINT"GIVE THE MONTH NUMBER, EG. 3 FOR MARCH
3001 PRINT#1,"GIVE THE MONTH NUMBER, EG. 3 FOR MARCH
3002 PRINT" FIRST MONTH";
3003 M$=3:PRINT#1," FIRST MONTH"; INPUTM4:PRINT#1,M4
3006 IFM4<0THEN3009:M5=0
3007 LETM5=0:GOTO3011
3009 PRINT" LAST MONTH";
3010 PRINT#1," LAST MONTH":INPUTM5:PRINT#1,M5
3011 PRINT" DO YOU WANT TO VARY ANOTHER FACTOR?";
3012 PRINT#1," DO YOU WANT TO VARY ANOTHER FACTOR?";
3013 GOTO5075
3030 IFOO=1THEN32850:PRINT#1," DO YOU WANT TO START AGAIN":OO=0
3040 PRINT"DO YOU WANT TO START AGAIN";
3050 GOSUB3880
3060 IF R$=" THEN 3850
3070 T6=0:M6=0:R$="":GOTO5
3080 INPUT R$":PRINT#1,R$
3090 IF R$="YES" THEN 3140
3100 IF R$="NO" THEN 3160
3110 PRINT#1,"TYPE EITHER YES OR NO"
3120 PRINT"TYPE EITHER YES OR NO"
3130 GOTO 3080
3140 LET R$=1
3150 GOTO 3170
3160 LET R$=0
3170 RETURN
3180 FORI0=1TO5:PRINT#1:NEXT:PRINT#1,"YEAR PHYTOPLANKTON\(X 1,000,000,000\)
3190 PRINT"YEAR PHYTOPLANKTON\(X 1,000,000,000\)
3200 PRINT#1,M9;" 0 100 200 300 400
3210 PRINTM9;" 0 100 200 300 400
3220 PRINT#1;" HERBIVORES\(X 1000,000\)
3230 PRINT" HERBIVORES\(X 1000,000\)
3240 PRINT#1," 0 20 40 60 80
3250 PRINT" 0 20 40 60 80
3260 IF M=3 THEN 3300
3270 PRINT#1,"#FISH#(ACTUAL NUMBER)"
3280 PRINT"#FISH#(ACTUAL NUMBER)"
3290 GOTO 3340
3300 PRINT#1,"#FISH#(ACTUAL NUMBER) FISH"
3310 PRINT"#FISH#(ACTUAL NUMBER) FISH"
3340 PRINT#1," 0 1000 2000 3000 4000"
3350 PRINT" 0 1000 2000 3000 4000 CAUGHT"
3360 PRINT#1,"+.....+.....+.....+.....+
3370 PRINT"+.....+.....+.....+.....+
3380 RETURN
3390 READ M$
3400 PRINT#1,M$;CHR$(141);
3410 PRINTM$;
3420 LET P5=P*(.8+.4*RND(0))
3430 LET H5=H*(.8+.4*RND(0))
3440 LET F5=F*(.9+.2*RND(0))
3450 IF ZZ=1 THEN 3480
3460 GOSUB 4140
3470 GOTO 3820
3480 LET P9=INT(P5/2E+10+8.5)
3490 LET H9=INT(H5/4E+68.5)
3500 LET F9=INT(F5/200+8.5)
3510 PRINTTAB(8);".";PRINT#1,TAB(8);".";CHR$(141);
3520 IF P9>79 THEN 3540
3530 GOTO 3560
3540 PRINT#1,TAB(79):"P":INT((P5/1E+09)+.5);CHR$(141);
3550 PRINT"P":INT((P5/1E+09)+.5);GOTO 3570
3560 PRINT"T":TAB(32);"P":PRINT#1,TAB(P9);"P":CHR$(141);
3570 IF P9=H9 THEN 3600
3580 PRINT"T":TAB(H9);"H":PRINT#1,TAB(H9);"H":CHR$(141);
3590 GOTO 3610
3600 PRINT"T":TAB(H9);"H":PRINT#1,TAB(H9);"H":CHR$(141);
3610 IF F9=H9 THEN 3640
3620 PRINT"T":TAB(F9);"H":PRINT#1,TAB(F9);"H":CHR$(141);
3630 GOTO 3620
3640 IF F9=H9 THEN 3670
3650 PRINT"T":TAB(F9);"H":PRINT#1,TAB(F9);"H":CHR$(141);
3660 GOTO 3690
3670 PRINT#1, TAB(9); "F"; CHR$(141);
3680 PRINT"J"; TAB(9); "F"
3690 IF M6=0 THEN 3730
3700 PRINT#1, TAB(40); "CLOSE"; CHR$(141);
3710 PRINT"J"; TAB(33); "CLOSE";
3720 GOTO 3770
3730 LET A7=INT(A7+.5)
3740 IF M6<>3 THEN 3770
3750 PRINT#1, TAB(40); A7; CHR$(141);
3760 PRINT"J"; TAB(33); A7;
3770 IF M6=3 THEN 3790
3780 PRINT#1: GOTO 3820
3790 LET A8=A8+A7
3800 PRINT#1
3810 PRINT"JW"
3820 RETURN
3830 DATA "JAN", "FEB", "MARCH", "APRIL", "MAY", "JUNE"
3840 DATA "JULY", "AUG", "SEPT", "OCT", "NOV", "DEC"
3850 PRINT#1
3860 PRINT#1, "END OF PROGRAMME"
3870 PRINT"END OF PROGRAMME"
3880 END
3890 IF AA>0 THEN 3970
3900 PRINT#1, "YEAR"; M9
3910 IF M6=3 THEN 3970
3920 PRINT#1, "MONTH PHYTO- HERBI- FISH"
3930 PRINT#1, " PLANKTON VORES"
3940 PRINT#1, " 9 6"
3950 PRINT#1, " (X10 ) (X10 )"
3960 GOTO 4010
3970 PRINT#1, "MONTH PHYTO- HERBI- FISH FISH"
3980 PRINT#1, " PLANKTON VORES CAUGHT"
3990 PRINT#1, " 9 6"
4000 PRINT#1, " (X10 ) (X10 )"
4010 IF AA>0 THEN 4090
4020 PRINT"JYEAR"; M9
4030 IF M6=3 THEN 4090
4040 PRINT"MONTH PHYTO- HERBI- FISH"
4050 PRINT" PLANKTON VORES"
4060 PRINT"9"  6
4070 PRINT"(X10)"  (X10)
4080 GOTO 4130
4090 PRINT"MONTH PHOTOPH - HERBICIDE - FISH CAUGHT"
4100 PRINT"PLANKTON VORES CAUGHT"
4110 PRINT"9"  6
4120 PRINT"(X10)"  (X10)
4130 RETURN
4140 IF M6=3 THEN 4190
4150 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4160 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5)
4170 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4180 GOTO 4300
4190 PRINT#1,SPC(7);INT(P5/1E+09+.5);CHR$(141);
4200 PRINT#1,SPC(25);INT(H5/1E+06+.5);CHR$(141);SPC(40);INT(F5+.5);CHR$(141);
4210 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
4220 IF M3=0 THEN 4260
4230 PRINT#1,SPC(51);"CLOSE"
4240 PRINT TAB(33);"CLOSE"
4250 GOTO 4300
4260 A7=INT(A7+.5)
4270 A8=A8+A7
4280 PRINT#1,SPC(51);A7
4290 PRINTTAB(33);A7
4300 CLOSE2:RETURN
4310 IF F9<>1 THEN 4440
4311 IF Z2=2 THEN 4440
4312 PRINT"DEC";TAB(8);"".
4320 PRINT"J";TAB(P9);"P"
4330 IF F9<0 H9 THEN 4360
4340 PRINT"J";TAB(H9);"*
4350 GOTO 4370
4360 PRINT"J";TAB(H9);"F"
4370 IF F9<P9 THEN 4400
4380 PRINT"J";TAB(F9);"*
4390 GOTO 4440
4400 IF F9<0 H9 THEN 4430
4410 PRINT"J";TAB(F9);"*
4420 GOTO 4440
4430 PRINT"J";TAB(F9);"F"
4440 RETURN
5000 PRINT": THIS PROGRAMME IS SIMULATION OF A FISH
5005 PRINT#1,"THIS PROGRAMME IS A SIMULATION OF A FISH
5006 PRINT"FARM.
5007 PRINT#1,"FARM.
5008 PRINT"YOU ARE REQUIRED TO FIND OUT AS MUCH AS
5009 PRINT#1,"YOU ARE REQUIRED TO FIND OUT AS MUCH AS
5010 PRINT"YOU CAN ABOUT THE ECOLOGY OF THE POND
5011 PRINT#1,"YOU CAN ABOUT THE ECOLOGY OF THE POND
5012 PRINT"YOU MANAGE.
5013 PRINT#1,"YOU MANAGE.
5014 PRINT"HOWEVER, THE FARM SHOULD MAKE A PROFIT.
5015 PRINT#1,"HOWEVER, THE FARM SHOULD MAKE A PROFIT.
5016 PRINT"I SUGGEST THAT YOU LOOK AT THE POND
5017 PRINT#1,"I SUGGEST THAT YOU LOOK AT THE POND
5018 PRINT"OVER A PERIOD OF SAY FIVE YEARS,
5019 PRINT#1,"OVER A PERIOD OF SAY FIVE YEARS,
5020 PRINT"OR SOME OTHER PERIOD YOU DECIDE FOR EACH SITUATION YOU SET UP.
5021 PRINT#1,"OR SOME OTHER PERIOD YOU DECIDE ON FOR EACH SITUATION YOU SET UP.
5022 PRINT"PRESS ANY KEY TO CONTINUE
5023 GETQ#: IFQW="THEN5023: GOTO5024
5024 PRINT"THE FISH FARM COSTS $1000 A YEAR TO RUN."
5025 PRINT#1,"THE FISH FARM COSTS $1000 A YEAR TO RUN.
5026 PRINT"INCOME CAN BE OBTAINED BY SELLING FISH AT $3 EACH AND
5027 PRINT#1,"INCOME CAN BE OBTAINED BY SELLING FISH AT $3 EACH AND
5028 PRINT"BY ALLOWING PEOPLE TO FISH AT A COST OF $10 EACH TIME THEY FISH.
5029 PRINT#1,"BY ALLOWING PEOPLE TO FISH AT A COST OF $10 EACH TIME THEY FISH.
5030 PRINT"PRESS ANY KEY TO CONTINUE
5031 GETQ#: IFQW="THEN5031: GOTO5036
5032 PRINT"RETURN
APPENDIX 12a

LISTING OF POND2HELP
10 SYS$0000: "C:OPEN1,4:PRINT"WHAT IS THE TIME":INPUTI$  
15 PRINT#1,"                PONDHELP"  
16 PRINT#1,"
20 PRINT#1,"TIME= ";TI$;DIM$(22),A$(30),LR(100),M$(2):GOSUB4080  
30 G=0: I$  
40 FORA=1TO5:PRINT#1:NEXT A  
70 GOTO 130  
80 ZC$="MODE?":PRINT#1,ZC$=PRINTZC$;  
90 GETR$:IFR$="THEN90  
100 M6=VAL(R$):PRINTM6:PRINT#1,M6  
110 IF (M6-1)*(M6-2)*(M6-3)*(M6-4)<0 THEN 130  
120 GOTO 230  
130 ZC$="YOU CAN:";ZC$="IM":PRINT#1,ZC$  
140 ZC$="MODE 1 OBSERVE THE POND":PRINT#1,ZC$=PRINTZC$  
150 ZC$="MODE 2 SET INITIAL NUMBERS OF":PRINTZC$=PRINT#1,ZC$  
160 ZC$="PHYTOPLANKTON, HERBIVORES":PRINTZC$=PRINT#1,ZC$  
170 ZC$="AND FISH":PRINTZC$=PRINT#1,ZC$  
180 ZC$="MODE 3 CATCH FISH":PRINTZC$=PRINT#1,ZC$  
190 ZC$="MODE 4 POLLUTE THE POND":PRINTZC$=PRINT#1,ZC$  
200 ZC$="TYPE 1,2,3 OR 4":PRINT"DON'T";ZC$="IM":PRINT#1,ZC$  
210 IF R$=1THEN220  
220 GOTO90  
230 R=0:U=0:U1=0:M9=0:P=1E+11:H=3.5E+07:F=1000  
240 P9=INT(P/3E+9+33.5):H9=INT(H/.6E+06+33.5):F9=INT(F/33.3+33.5)  
245 XXX=P9:HH9=H9:FF9=F9  
250 REM  
260 BB7=INT(A7/(33.3/4)+.5)  
270 IF M6=4THEN360  
310 PRINT"DO YOU WANT A GRAPH(1) OR A TABLE(2)?";  
311 PRINT#1,"DO YOU WANT A GRAPH (1) OR A TABLE (2)?";  
320 GETR$:IFR$="THEN320  
330 ZZ=VAL(R$)  
340 PRINTZZ:PRINT#1,ZZ:GOTO370  
350 REM  
360 ZZ=2  
370 IF M6>2 THEN 680  
380 PRINT#1,"WHAT ARE THE INITIAL NUMBERS OF"  
390 PRINT#1,"WHAT ARE THE INITIAL NUMBERS OF"  
400 PRINT#1,"PHYTOPLANKTON(0-250)x1,000,000,000?"  
410 PRINT"PHYTOPLANKTON(0-250)x1,000,000,000";  

420 INPUT P:PRINT#1,P
430 IF P<(250-P)>=0 THEN 470
440 PRINT#1,"****NOT MORE THAN 250 NOR LESS THAN 0?"
450 PRINT"****NOT MORE THAN 250 NOR LESS THAN 0?"
460 GOTO 420
470 IF P=0*1E+09
480 XG=INT(P/3.33E+9+33.5)
500 IF XG=INT(P/3.33E+9+33.5)
510 INPUT H:PRINT#1,H
520 IF H<(50-H)>=0 THEN 560
530 ZC$="***NOT MORE THAN 50 NOR LESS THAN 0"
540 ZC$="***NOT MORE THAN 50 NOR LESS THAN 0"
550 GOTO 520
560 LET H=H*1E+06
570 HH9=INT(H/6.7E+06+33.5)
580 PRINT#1,"FISH(<1000)"
590 PRINT"FISH(<1000)"
600 INPUT F:PRINT#1,F
610 FF9=INT(F/33.3+33.5)
620 IF FF9=F THEN 650
630 ZC$="***YOU CAN ONLY HAVE COMPLETE FISH?"
640 GOTO 600
650 IF F<(1000-F)>=0 THEN 830
660 ZC$="***NOT MORE THAN 1000 NOR LESS THAN 0"
670 GOTO 580
680 IF M>4 THEN 830
690 ZC$="WHAT LEVEL OF POLLUTION":PRINT"M";ZC$:PRINT#1,ZC$
700 ZC$="LOW (1), MODERATE (2) OR HIGH (3)?":PRINTZC$:PRINT#1,ZC$
710 INPUT U:PRINT#1,U
720 IF (U-1)<(U-2)<(U-3)=0 THEN 750
730 ZC$="***TYPE 1, 2 OR 3":PRINTZC$:PRINT#1,ZC$
740 ,21750
750 ZC$="WHEN DOES IT START?":PRINTZC$:PRINT#1,ZC$
755 ZC$="(TYPE THE MONTH NO., EG 3 FOR MARCH)":PRINTZC$:PRINT#1,ZC$
760 INPUT U4:PRINT#1,U4
770 IF U4=INT(U4) THEN 790
780 IF U4=INT(U4) THEN 790
790 ZC$="***GIVE THE MONTH NUMBER, EG. 3 FOR MARCH":PRINTZC$:PRINT#1,ZC$
800 GOTO 760
810 LET U5=U4+1
LET U1=1
LET A=0
LET M4=0
LET M5=0
IF M6<>3 THEN 1210
ZC$="HOW MANY FISHERMEN <0-20>?":PRINT"":ZC$=PRINT#1,ZC$
REM
INPUT A:PRINT#1,A
IF A=INT(A) THEN 930
ZC$="***YOU CAN ONLY HAVE COMPLETE FISHERMEN":PRINTZC$=PRINT#1,ZC$
GOTO 870
IF A*(20-A)>=0 THEN 960
ZC$="***NOT MORE THAN 20 NOR LESS THAN 0 FISHERMEN":PRINTZC$=PRINT#1,ZC$
GOTO 870
IF A=0 THEN 1210
ZC$="FISHING FREQUENCY?<ONLY 1,2 OR 4 TIMES A MONTH>":PRINTZC$=PRINT#1,ZC$
INPUT A1:PRINT#1,A1
IF(A1-1)*A1*(A1-4)=0 THEN 1030
ZC$="***YOU CAN FISH 1,2 OR 4 TIMES A MONTH":PRINTZC$=PRINT#1,ZC$
FOR A=1 TO 4000:NEXT
GOTO 980
LET A2=4
IF A1<>2 THEN 1070
LET A2=2
GOTO 1090
IF A1<>4 THEN 1090
LET A2=1
PRINT#1,
ZC$="WHAT ARE THE MONTHS OF THE CLOSE SEASON?":PRINTZC$=PRINT#1,ZC$
ZC$="GIVE THE MONTH NUMBER EG.3 FOR MARCH":PRINTZC$=PRINT#1,ZC$
ZC$="IF YOU DO WANT A CLOSE SEASON THEN TYPE '0'":PRINTZC$=PRINT#1,ZC$
INPUT M4:PRINT#1,M4
IF M4=0 THEN 1210
IF M4>INT(M4) THEN 1110
IF (M4-1)*(12-M4)<0 THEN 1110
ZC$="LAST MONTH?":PRINTZC$=PRINT#1,ZC$
1180 INPUT M5:PRINT#1,M5
1190 IF M5>INT(M5) THEN 1110
1200 IF (M5-1)*{(12-M5)<0} THEN 1110
1210 IF ZZ<1 THEN 270
1220 IF ZZ>2 THEN 270
1230 LET M9=M9+1
1235 IF ZZ=2 THEN 1280
1240 DOPEN#4,"RESULTS",L10,D1:NA=NA+1:RECORD#4,(NA):PRINT#4,ZZ
1250 NA=NA+1:RECORD#4,(NA):PRINT#4,M6
1260 NA=NA+1:RECORD#4,(NA):PRINT#4,M9
1270 DCLose#4
1275 GOSUB20000
1280 IF ZZ=2 THEN 1300
1290 GOTO 1320
1300 REM
1310 GOTO 1330
1320 GOSUB 3110
1330 IF ZZ=2 THEN 1350
1340 GOTO 1360
1350 REM
1360 LET M2=0
1370 LET M=0
1380 LET A8=0
1390 RESTORE
1400 LET I=0
1410 LET A7=0
1420 LET M=M+1
1430 LET M1=0
1440 LET I=I+1
1450 LET M1=M1+7
1460 LET S=SIH((M*28+M1-78)*.0187)
1470 IF H>0 THEN 1510
1480 LET H1=0
1490 LET H2=0
1500 GOTO 1670
1510 LET H1=H/H
1520 IF H1>7000 THEN 1560
1530 IF H1<100 THEN 1580
1540 LET H1=4800*(H1-100)/6900
1550 GOTO 1590
1560 LET H1=4000
1570 GOTO 1590
1580 LET H1=0
1590 LET H2=P/1000
1600 IF H2>1E07 THEN 1640
1610 IF H2<1000 THEN 1660
1620 LET H2=(H2-1000)/9.999E+06
1630 GOTO 1670
1640 LET H2=1
1650 GOTO 1670
1660 LET H2=0
1670 LET H3=H1*H2
1680 LET H4=H3*H1
1690 IF F>0 THEN 1720
1700 LET F1=0
1710 GOTO 1820
1720 IF F>.1 THEN 1740
1730 LET F=.1
1740 LET F1=H/F
1750 IF F1>200 THEN 1790
1760 IF F1<20 THEN 1810
1770 LET F1=100*(F1-20)/180
1780 GOTO 1820
1790 LET F1=100
1800 GOTO 1820
1810 LET F1=0
1820 LET S1=S*1E+10+1.4E+11
1830 LET S2=S+4
1840 LET P1=(P-H4/1.8)*.45
1850 IF(P+P1)/2<=S1 THEN 1900
1860 LET P2=(P+P1)/2-S1
1870 LET S2=S2-(S2-1)*P2/S1
1880 IF S2>1 THEN 1900
1890 LET S2=1
1900 LET P=P1*S2
1910 IF U1=0 THEN 1970
1920 IF (M-U4)*(M-U5)>0 THEN 1970
1930 IF U=3 THEN 1960
1940 LET P=P*4
1950 GOTO 1970
1960 LET P=P/4
1970 IF F>0 THEN 1990
1980 LET P=0
1990 LET H=(H-F*F1*20)*(H1*.000045+.8)*(H3*.00005+1)
2000 IF U1=0 THEN 2040
2010 IF U=1 THEN 2040
2020 IF (M-U4)*(M-U5)<0 THEN 2040
2030 LET H=H/2
2040 IF H>0 THEN 2060
2050 LET H=0
2060 LET F7=.27
2070 IF (M-4)*(10-M)<0 THEN 2090
2080 LET F7=F7-F1*.0017
2090 LET F6=F*F7
2100 IF (M-4)*(M-5)<0 THEN 2170
2110 IF F<3000 THEN 2150
2120 IF F>4000 THEN 2170
2130 LET F8=1-(F-3000)/1000
2140 GOTO 2180
2150 LET F8=1
2160 GOTO 2180
2170 LET F8=0
2180 LET F=F6*(1+F8*F1*.003)
2190 IF U=0 THEN 2220
2200 IF (M-U4)*(M-U5)<0 THEN 2220
2210 LET F=F/U/1.28
2220 IF F>1 THEN 2240
2230 LET F=0
2240 LET M3=0
2250 IF A=0 THEN 2460
2260 IF M4=M5 THEN 2290
2270 IF (M-M4)*(M5-M)<0 THEN 2320
2280 GOTO 2300
2290 IF (M-M4)*(M5-M)<0 THEN 2320
2300 LET M3=1
2310 GOTO 2460
2320 LET M2=M2+1
2330 IF A2<M2 THEN 2460
2340 LET M2=0
2350 IF F>4000 THEN 2390

2360 IF F<50 THEN 2410
2370 LET A3=25*(F-50)/3950
2380 GOTO 2420
2390 LET A3=25
2400 GOTO 2420
2410 LET A3=0
2420 LET A3=A3*2*RND(0)
2430 LET A6=A3*A
2440 LET A7=A7+A6
2450 LET F=F-A6
2460 IF M1<28 THEN 1440
2470 GOSUB3470
2480 IF I<48 THEN 1410
2490 IF M6<3 THEN 2540
2500 PRINT#1,"NUMBER OF FISH CAUGHT DURING
2510 PRINT#1,"THE YEAR=";A8
2520 IFZZ=2THEN2540
2530 AL$="TOTAL FISH CAUGHT= "+STR$(INT(A8+.5));H,AL$,130,165
2540 PRINT#1;PRINT#1,"CONTINUE?";
2550 PRINT"";H,AL$,130,165,CONTINUE! ?";
2560 REM
2570 RESTORE
2580 GOSUB 2980
2590 PRINT"";H,AL$,130,165
2600 GOSUB4270
2610 !C:PRINT#1,""                         TIME=";TI$
2620 IFR9=1THEN2710
2630 IFLL<=2THEN2830
2640 PRINT":";
2650 PRINT"";H,AL$,130,165,IF HELP REQUIRED PRESS 'Y'
2660 PRINT"";H,AL$,130,165,IF NO HELP REQUIRED PRESS 'RETURN'
2670 GETM$
2680 IFM$="Y"THEN2690
2685 GOSUB5570
2686 GOTO 2710
2690 IFM$=CHR$(13)THEN2710
2700 GOTO2670
2710 IF R9=1 THEN 2750
2720 IF M6=4 THEN 2790
2730 IF M6=3 THEN 2850
2740 GOTO 2780
2750 LET R=1
2760 LET U1=0
2770 GOTO 1230
2780 IF M6<4 THEN 2850
2790 PRINT1." DIFFERENT LEVEL OF POLLUTION";
2800 PRINT"(VARIATION OF DIFFERENT LEVEL OF POLLUTION)";
2810 GOSUB 2980
2820 IF R9=1 THEN 2840
2830 GOTO 2930
2840 GOTO 230
2850 IF M6<3 THEN 2930
2860 PRINT1." DIFFERENT FISHING RATE OR CLOSE SEASON";
2870 PRINT"(VARIATION OF DIFFERENT FISHING VALUES)";
2880 GOSUB 2980
2890 IF R9=1 THEN 2910
2900 GOTO 2930
2910 LET R=2
2920 GOTO 850
2930 PRINT1." DO YOU WANT TO START AGAIN (GO BACK TO CHOOSE A MODE) ";
2940 PRINT"(VARIATION OF DIFFERENT FISHING VALUES)";
2950 GOSUB 2980
2960 IF R9=0 THEN 3740
2970 R9=0:GOTO 130
2980 GETR$:IFR$="THEN2980
2990 IFR$="Y"THENR$="YES"
3000 IFR$="N"THENR$="NO"
3010 PRINT1,R$:PRINTR$
3020 IF R$="YES" THEN 3070
3030 IF R$="NO" THEN 3080
3040 PRINT1,"TYPE EITHER YES OR NO"
3050 PRINT"TYPE EITHER YES OR NO"
3060 GOTO 2980
3070 LET R9=1
3080 GOTO 3100
3090 LET R9=0
3100 RETURN
3110 PRINT"I;:C;;B::L,0,33,319,33
3120 !L,30,33,30,153
3130 !L,55,33,55,153

(appendix 12a)
3540 LET P9=INT(P5/3.33E+9+33.5)
3550 LET H9=INT(H5/6.7E+06+33.5)
3560 LET F9=INT(F5/33.3+33.5)
3570 B7=INT(A7/(33.3/4)+.5)
3580 IL,(M-1)*20+79,FF9,M*20+79,F9
3590 IV=0:DI=0
3600 FORS=(M-1)+.1TOSTEP.1
3610 IV=(H9-HH9)/10:DI=DI+IV
3620 IF,GS*20+79,HH9+DI
3630 NEXTGS
3640 FORTT=1TO3:IL,(M-1)*20+79,(XX9+2-TT),M*20+79,(P9+2-TT)
3650 NEXTTT
3660 FORT=0TO1STEP.25
3670 FORYY=1TO5STEP2
3680 IL,(M-1+T)*20+79,33,(M-1+T)*20+79,BB7+((B7-BB7)*T)+33
3690 NEXTYY
3700 NEXTT
3715 GOSUB200000
3720 AS=A9+A7
3730 RETURN
3740 PRINT#1
3750 PRINT"1","END OF PROGRAMME"
3760 PRINT"END OF PROGRAMME"
3770 END
3780 REM
3790 READM$
3800 DATA"JAN","FEB","MARCH","APRIL","MAY","JUNE"
3810 DATA"JULY","AUG","SEPT","OCT","NOV","DEC"
3820 IFM$="JAN"THEN3840
3830 GOTO3950
3840 PRINT"YEAR";M9
3841 PRINT#1,"$YEAR";M9
3850 IFM$="DEC"THEN3910
3860 PRINT"MONTH PHYTO HERBI FISH"
3861 PRINT#1,"MONTH PHYTO HERBI FISH"
3870 PRINT"PLANKTON VORES"
3871 PRINT#1," PLANKTON VORES"
3880 PRINT"",9,5
3881 PRINT#1,"",9,6
3890 PRINT"(X10)(X10)
3891 PRINT#1,"(X10)(X10)
3900 GOTO3950
3910 PRINT"MONTH PHYTO-M HERBI- FISH FISH"
3911 PRINT#1,"MONTH PHYTO-M HERBI- FISH FISH"
3920 PRINT"PLANKTON VORES CAUGHT"
3921 PRINT#1,"PLANKTON VORES CAUGHT"
3930 PRINT"9 9"
3931 PRINT#1,"(X10)(X10)
3940 PRINT"(X10)(X10)
3941 PRINT#1,"(X10)(X10)
3950 PRINTM:
3951 PRINT#1,M$;IFM=3THEN3980
3960 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
3961 PRINT#1,CHR$(141)SPC(6);INT(P5/1E+09+.5)
3962 PRINT#1,CHR$(141)SPC(6);INT(P5/1E+09+.5)
3963 PRINT#1,CHR$(141)SPC(25);INT(F5+.5)
3970 GOTO4070
3980 PRINTTAB(6);INT(P5/1E+09+.5);TAB(16);INT(H5/1E+06+.5);TAB(25);INT(F5+.5)
3990 IFN=0THEN4020
4000 PRINTTAB(33);"CLOSE"
4001 PRINT#1,CHR$(141)SPC(33);"CLOSE"
4010 GOTO4070
4020 A7=INT(A7+.5)
4030 A8=A8+A7
4040 PRINTTAB(33);A7
4041 PRINT#1,CHR$(141)SPC(33);A7
4050 IFM$="DEC"THEN4070
4060 PRINT"TOTAL NUMBER OF FISH CAUGHT=";A8
4061 PRINT#1,"TOTAL NUMBER OF FISH CAUGHT=";A8
4070 RETURN
4080 REM**SUBROUTINES TO DETERMINE LEVEL OF UNDERSTANDING**
4090 IFG=1THEN4270
4100 PRINT"HELLOWWW"
4110 ZC$="I AM GOING TO TRY AND HELP YOU";PRINTZC$;PRINT#1,ZC$
4120 ZC$="UNDERSTAND HOW A POND ECOSYSTEM BEHAVES.";PRINTZC$;PRINT#1,ZC$
4130 ZC$="FOR ME TO HELP YOU UNDERSTAND HOW AN";PRINTZC$;PRINT#1,ZC$
4140 ZC$="ECOSYSTEM BEHAVES UNDER A VARIETY OF":PRINTZC$:PRINT#1,ZC$
4150 ZC$="SITUATIONS, YOU WILL HAVE TO TELL ME":PRINTZC$:PRINT#1,ZC$
4160 ZC$="WHAT YOU KNOW AT VARIOUS TIMES DURING":PRINTZC$:PRINT#1,ZC$
4170 ZC$="THE PROGRAM RUN":PRINTZC$:PRINT#1,ZC$
4180 PRINT" Press any key to continue"
4190 GETR$:IFR$="THEN4190"
4200 ZC$="BY TELLING ME WHAT YOU KNOW I CAN":PRINT"J";ZC$:PRINT#1,ZC$
4210 ZC$="COOPERATE WITH YOU BY MAKING SUGGESTIONS":PRINTZC$:PRINT#1,ZC$
4220 ZC$="AS TO WHAT I THINK YOU SHOULD BE TRYING":PRINTZC$:PRINT#1,ZC$
4230 ZC$="TO DO... BUT ONLY IF YOU ASK ME TO HELP YOU":PRINTZC$:PRINT#1,ZC$
4240 PRINT" Press any key to continue"
4250 GETR$:IFR$="THEN4250"
4260 Q=Q+1
4270 PRINT"J";:!C
4280 ZC$="IN THE FOLLOWING TABLE I HAVE HAD TO":PRINT"J";ZC$:PRINT#1,ZC$
4290 ZC$="USE SOME ABBREVIATIONS":PRINTZC$:PRINT#1,ZC$
4300 ZC$="F=FISH":PRINTZC$:PRINT#1,ZC$
4310 ZC$="H=HERBIVORES":PRINTZC$:PRINT#1,ZC$
4320 ZC$="P=PHYTOPLANKTON":PRINTZC$:PRINT#1,ZC$
4330 PRINT" Press any key to continue"
4340 GETR$:IFR$="THEN4340"
4350 ZC$="IN THE FOLLOWING TABLE I WANT YOU TO":PRINT"J";ZC$:PRINT#1,ZC$
4360 ZC$="TELL ME IF YOU KNOW THE FOLLOWING":PRINTZC$:PRINT#1,ZC$
4370 ZC$="STATEMENTS TO BE TRUE":PRINTZC$:PRINT#1,ZC$
4380 ZC$="PRESS '1' IF YOU KNOW IT TO BE TRUE":PRINT"J";ZC$:PRINT#1,ZC$
4390 ZC$="PRESS '0' IF YOU DON'T KNOW IT TO BE TRUE":PRINTZC$:PRINT#1,ZC$
4400 PRINT" Press any key to continue"
4410 GETR$:IFR$="THEN4410"
4420 PRINT"J";:!B;:!C
4430 !L.0,100,319,100
4440 !L.319,100,319,84
4450 !L.319,84,0,84
4460 !L.8,84,0,100
4470 !L.300,84,300,100
4480 DOPEN#3,"REPLIES",L2,D0
4490 DOPEN#2,"DATA",D0
4500 LL=LL+1
4510 REM**RANDOMLY SELECT A QUESTION**
4520 W=INT(RND(0)*21+.5)
4530  WE=0:WF=0:LA=0:LB=0
4540  IF WF=0 THEN 4520
4550  REM**CHECK TO SEE RANDOM NO. CORRESPONDS TO AN AVAILABLE QU.**
4560  IF WE AND W=21 THEN LA=1
4570  IF WE=W THEN 5220
4580  IF WF=W THEN 5220
4590  REM**PRINT QUESTION**
4600  RECORD#2, (W) :
4610  INPUT#2, S$ ;
4620  PRINT"T H E Q U E S T I O N I S :" ;
4630  PRINT$ ;
4640  PRINT"T H E A N S W E R I S :" ;
4650  REM**ASK FOR ANSWER TO QU.**
4660  PRINT"H O W M A N Y ?"
4670  GETR$(W):IFR$(W)="THEN4665
4680  REM**PRINT QU'S AND ANSWERS**
4690  OPEN#6, 4:PRINT#6, W, S$, R$(W):CLOSE$ 6
4700  AQ=W
4710  REM**STOP ASKING QU'S IF HAVE ARRIVED AT QU.NO.1 OR NO.21**
4720  IFLA=1 THEN 5220
4730  IFLB=1 THEN 5220
4740  IFAQ=1360:GOTO4760
4750  ON AQ GOTO4780, 4800, 4820, 4840, 4860, 4880, 4900, 4920, 4940, 4960, 4980, 5000, 5020
4760  AQ=AQ-13
4770  ON AQ GOTO 5040, 5060, 5080, 5100, 5120, 5140, 5160, 5180
4780  IFR$(1)="Y" GOTO5460
4790  GOTO5380
4800  IFR$(2)="Y" GOTO5460
4810  GOTO5380
4820  IFR$(3)="Y" GOTO5460
4830  GOTO5380
4840  IFR$(4)="N" GOTO5460
4850  GOTO5380
4860  IFR$(5)="N" GOTO5460
4870  GOTO5380
4880  IFR$(6)="Y" GOTO5460
4890  GOTO5380
4900  IFR$(7)="Y" GOTO5460
4910  GOTO5380
4920 IFR$(8)="Y"GOT05460  
4930 GOT05380  
4940 IFR$(9)="Y"GOT05460  
4950 GOT05380  
4960 IFR$(10)="N"GOT05460  
4970 GOT05380  
4980 IFR$(11)="N"GOT05460  
4990 GOT05380  
5000 IFR$(12)="Y"GOT05460  
5010 GOT05380  
5020 IFR$(13)="Y"GOT05460  
5030 GOT05380  
5040 IFR$(14)="Y"GOT05460  
5050 GOT05380  
5060 IFR$(15)="Y"GOT05460  
5070 GOT05380  
5080 IFR$(16)="Y"GOT05460  
5090 GOT05380  
5100 IFR$(17)="Y"GOT05460  
5110 GOT05380  
5120 IFR$(18)="Y"GOT05460  
5130 GOT05380  
5140 IFR$(19)="Y"GOT05460  
5150 GOT05380  
5160 IFR$(20)="Y"GOT05460  
5170 GOT05380  
5180 IFR$(21)="Y"GOT05200  
5190 WE=21:GOT05210  
5200 GOT05380  
5210 REM**STORE LEVEL OF UNDERSTANDING IN FILE-REPLIES**  
5220 REM**  
5230 RECORD#3,LL)  
5240 PRINT#3,WE  
5250 DCLOSE#2  
5260 DCLOSE#3  
5270 RETURN  
5280 REM**ROUTINE TO SELECT AN EASIER QUI.**  
5290 IFW=1THEN5220  
5300 IFW=21THEN5220  
5310 IFWF=WTHEN5220
5420 WF=W
5430 W=INT((W-WE)/2+WE)
5440 IFW=1 THENLB=LB+1
5450 GOTO5560
5460 REM**ROUTINE TO SELECT A MORE DIFFICULT QU.**
5470 IFW<1 THEN5220
5480 IFW>21 THEN5220
5490 IFWE=W THEN5220
5500 WE=W
5510 IFWF=0 THEN5530
5520 GOTO5550
5530 W=INT((21-W)/2+W+.5)
5540 GOTO5460
5550 W=INT((WF-W)/2+W+.5)
5560 GOTO5460
5570 REM**ROUTINES TO PROVIDE HELP TO STUDENT UPON REQUEST**
5580 REM**ROUTINE TO FIND PAST LEVELS OF UNDERSTANDING**
5590 IOPEN#3,"REPLIES",10
5600 FORLO=1 TO LL
5620 RECORD#3,(LO)
5630 INPUT#3,R$
5650 LR(LO)=VAL(R$)
5660 NEXT LO
5690 DCLOSE#3
5700 REM**ROUTINE TO DETERMINE MEAN L.O.U.**
5710 LU=0;LY=0;LX=0;MA=0
5720 FORLO=1 TO LL
5730 IFV<LR(LO) THENLv=LR(LO); REM**HIGHEST L.O.U.**
5740 LU=LU+LR(LO); REM**TOTAL L.O.U**
5750 NEXT LO
5755 LL=3
5760 LY=LU/LL; REM**MEAN L.O.U.**
5770 IFWE<LY THEN5810
5780 IFWE=LY THEN5820
5790 GOTO5830
5800 MO=WE+1; GOTO5850
5810 MO=INT(LY+.5); GOTO5850
5820 MO=INT(LY+1.5); GOTO5850
5830 MO=INT(WE+1.5); GOTO5850
5850 IFMO=0 THEN MO=1
5855 GOSUB5930
5860 MA=MA+1:IF MA>1THEN5970
5870 PRINT"***PRESS 'C' TO GO BACK TO THE PROGRAM";
5880 PRINT"***PRESS 'C' TO GO BACK TO THE PROGRAM"
5890 PRINT"***PRESS 'R' FOR ANOTHER SUGGESTION"
5900 PRINT"***PRESS 'R' FOR ANOTHER SUGGESTION"
5910 GETR$:IFR$="" THEN5910:PRINT#1,R$
5920 IFR$="C" THEN5970
5930 IFR$="R" THEN5950
5940 GOTO5910
5950 MO=MO+1
5960 GOSUB5930
5970 RETURN
5980 ZC$="I HAVE LOOKED AT THE ANSWERS YOU HAVE":PRINT"J":ZC$:PRINT#1,ZC$
5990 ZC$="GIVEN TO MY QUESTIONS THROUGHOUT THIS":PRINTZC$:PRINT#1,ZC$
6000 ZC$="PROGRAM RUN."":PRINTZC$:PRINT#1,ZC$
6010 ZC$="I AM NOW GOING TO MAKE A SUGGESTION AS":PRINTZC$:PRINT#1,ZC$
6020 ZC$="HOW YOU COULD BEST USE THIS PROGRAM AT":PRINTZC$:PRINT#1,ZC$
6030 ZC$="THIS MOMENT.  I HOPE THAT THIS WILL":PRINTZC$:PRINT#1,ZC$
6040 ZC$="ENABLE YOU TO UNDERSTAND HOW THE POND IS":PRINTZC$:PRINT#1,ZC$
6050 ZC$="BEHAVING."":PRINTZC$:PRINT#1,ZC$
6060 ZC$="IF YOU FIND THAT YOU HAVE ALREADY":PRINTZC$:PRINT#1,ZC$
6070 ZC$="Pursued this idea, I will make another":PRINTZC$:PRINT#1,ZC$
6080 ZC$="SUGGESTION WHICH MIGHT HELP YOU."":PRINTZC$:PRINT#1,ZC$
6090 PRINT"***PRESS ANY KEY TO CONTINUE"
6100 GETR$:IFR$="" THEN6100
6110 REM**ROUTINE TO PRESENT AN EASY SUGGESTION WHICH MIGHT HELP THE STUDENT**
6120 IFMO>21THENMO=21
6130 IFMO>12THEN6160
6140 ON MO GOTO 6180,6190,6200,6210,6220,6230,6240,6250
6160 MO=MO-12
6170 ON MO GOTO 6260,6270,6280,6290,6300,6310,6320,6330,6340
6180 AS=1:GOTO6350
6190 AS=2:GOTO6350
6200 AS=3:GOTO6350
6210 AS=4:GOTO6350
6220 AS=5:GOTO6350
6230 AS=6:GOTO6350
6240 AS=7:GOTO6350
6250 AS=8:GOTO6350
PRINT "THE POPULATIONS ARE INTERDEPENDENT.
PRINT "AND DESIGN AND RUN AN EXPERIMENT WHICH
PRINT "WILL PROVE OR DISPROVE THIS SUPPOSITION."
PRINT "PERHAPS YOU COULD DO THIS BY REMOVING A" 
PRINT "POPULATION FROM THE POND."
PRINT "PRESS ANY KEY TO CONTINUE
GETIU$:IFIU$=""THEN770
RETURN
PRINT "YOU HAVE SAID THAT THE"
IFR$<5>"N"THEN6850
PRINT "FISH ARE NOT PROPORTIONAL TO THE HERBIVORES.";ZY=1
PRINT "FISH ARE NOT PROPORTIONAL TO THE HERBIVORES.";ZY=1
IFR$<1>"V"THEN6890
IFZY<1THEN6870:PRINT "AND THE";ZY=0
PRINT "FISH ARE PROPORTIONAL TO THE HERBIVORES AND PLANKTON";ZY=1
PRINT "FISH ARE PROPORTIONAL TO THE HERBIVORES AND PLANKTON";ZY=1
IFR$<13>"V"THEN6930
IFZY<1THEN6910:PRINT "AND THE";ZY=0
PRINT "FISH ARE PROPORTIONAL TO THE PLANKTON.
PRINT "FISH ARE PROPORTIONAL TO THE PLANKTON.
PRINT "I CAN SUGGEST THAT YOU TRY AND VARY THE
PRINT "I CAN SUGGEST THAT YOU TRY AND VARY THE
PRINT "POPULATION SIZES TO SEE WHETHER THE FISH"
PRINT "POPULATION SIZES TO SEE WHETHER THE FISH"
PRINT "RESPOND/DO NOT RESPOND TO THESE CHANGES."
PRINT "RESPOND/DO NOT RESPOND TO THESE CHANGES."
PRINT "PRESS ANY KEY TO CONTINUE
GETIU$:IFIU$=""THEN7000
RETURN
PRINT "YOU HAVE SAID THAT THE HERBIVORES ARE
PRINT "YOU HAVE SAID THAT THE HERBIVORES ARE
PRINT "NOT PROPORTIONAL TO THE PLANKTON.
PRINT "NOT PROPORTIONAL TO THE PLANKTON.
PRINT "IT MIGHT BE FRUITFUL FOR YOU TO
7070 PRINT#1,"IT MIGHT BE FRUITFUL FOR YOU TO
7080 PRINT"INVESTIGATE THIS MATTER A LITTLE MORE."
7090 PRINT#1,"INVESTIGATE THIS MATTER A LITTLE MORE."
7100 PRINT"HOW WOULD YOU SEE WHETHER THE HERBIVORES";
7110 PRINT#1,"HOW WOULD YOU SEE WHETHER THE HERBIVORES";
7120 PRINT"WERE PROPORTIONAL TO THE PLANKTON"
7130 PRINT#1,"WERE PROPORTIONAL TO THE PLANKTON"
7140 INPUT"WHAT WOULD YOU VARY";AT$
7150 PRINT#1,"WHAT WOULD YOU VARY";AT$
7160 IF AT$="PLANKTON"THEN7210
7170 IF AT$="PHYTOPLANKTON"THEN7210
7180 PRINT"TRY AGAIN"
7190 PRINT#1,"TRY AGAIN"
7200 GOTO7140
7210 PRINT"O.K. TRY IT"
7220 PRINT#1,"O.K. TRY IT"
7230 PRINT"PRESS ANY KEY TO CONTINUE"
7240 GETI$: IFI$=""THEN7240
7250 RETURN
7260 PRINT"HAVING REALISED THAT THE FISH ARE
7270 PRINT#1,"HAVING REALISED THAT THE FISH ARE
7280 PRINT"PROPORTIONAL TO THE HERBIVORES, AND THE
7290 PRINT#1,"PROPORTIONAL TO THE HERBIVORES, AND THE
7300 PRINT"HERBIVORES ARE PROPORTIONAL TO THE
7310 PRINT#1,"HERBIVORES ARE PROPORTIONAL TO THE
7320 PRINT"PLANKTON, I THINK PERHAPS YOU SHOULD
7330 PRINT#1,"PLANKTON, I THINK PERHAPS YOU SHOULD
7340 PRINT"VARY ONE OF THESE POPULATIONS TO SEE ITS
7350 PRINT#1,"VARY ONE OF THESE POPULATIONS TO SEE ITS
7360 PRINT"EFFECT ON THE OTHER TWO POPULATIONS.
7370 PRINT#1,"EFFECT ON THE OTHER TWO POPULATIONS.
7380 PRINT"CONSIDER CAREFULLY WHICH OF THE
7390 PRINT#1,"CONSIDER CAREFULLY WHICH OF THE
7400 PRINT"POPULATIONS YOU SHOULD VARY.
7410 PRINT#1,"POPULATIONS YOU SHOULD VARY.
7420 PRINT"PRESS ANY KEY TO CONTINUE"
7430 GETI$: IFI$=""THEN7430
7440 RETURN
7450 PRINT"SO FAR YOU APPEAR TO HAVE REALISED
7460 PRINT#1,"SO FAR YOU APPEAR TO HAVE REALISED
7470 PRINT"THAT THE POPULATIONS IN THE POND ARE
7480 PRINT#1,"THAT THE POPULATIONS IN THE POND ARE
7490 PRINT"INTERDEPENDENT. YOU APPEAR TO HAVE
7500 PRINT#1,"INTERDEPENDENT. YOU APPEAR TO HAVE
7510 PRINT"REALISED ALSO THAT THE FISH ARE
7520 PRINT#1,"REALISED ALSO THAT THE FISH ARE
7530 PRINT"PROPORTIONAL TO THE HERBIVORES, AND THAT";
7540 PRINT#1,"PROPORTIONAL TO THE HERBIVORES, AND THAT"
7550 PRINT"THE HERBIVORES ARE PROPORTIONAL TO THE
7560 PRINT#1,"THE HERBIVORES ARE PROPORTIONAL TO THE
7570 PRINT"PLANKTON.
7580 PRINT#1,"PLANKTON.
7590 IF R$(3)="N" THEN 7640
7600 PRINT"YOU ALSO BELIEVE THAT THE FISH FEED ON
7610 PRINT#1,"YOU ALSO BELIEVE THAT THE FISH FEED ON
7620 PRINT"THE HERBIVORES";: JK=1
7630 PRINT#1,"THE HERBIVORES";: JK=1
7640 IF R$(4)="N" THEN 7660:
7650 IF JK<1 THEN 190**
7660 PRINT"AND THE HERBIVORES FEED ON PLANKTON"
7670 PRINT#1,"AND THE HERBIVORES FEED ON PLANKTON"
7680 GOTO 7750
7690 PRINT"YOU ALSO BELIEVE THAT THE FISH FEED ON
7700 PRINT#1,"YOU ALSO BELIEVE THAT THE FISH FEED ON
7710 PRINT"THE HERBIVORES, BUT THE HERBIVORES DO
7720 PRINT#1,"THE HERBIVORES, BUT THE HERBIVORES DO
7730 PRINT"NOT FEED ON THE PLANKTON.
7740 PRINT#1,"NOT FEED ON THE PLANKTON.
7750 PRINT"WHY NOT TRY LOOKING AT HOW THIS
7760 PRINT#1,"WHY NOT TRY LOOKING AT HOW THIS
7770 PRINT"INTERDEPENDENCE OF POPULATIONS YOU HAVE
7780 PRINT#1,"INTERDEPENDENCE OF POPULATIONS YOU HAVE
7790 PRINT"INDICATED THAT YOU BELIEVE TO EXIST
7800 PRINT#1,"INDICATED THAT YOU BELIEVE TO EXIST
7810 PRINT"MIGHT ACTUALLY TAKE PLACE.
7820 PRINT#1,"MIGHT ACTUALLY TAKE PLACE.
7830 PRINT"HOW MIGHT THE SIZE OF THE POPULATIONS
7840 PRINT#1,"HOW MIGHT THE SIZE OF THE POPULATIONS
7850 PRINT"BE GOVERNED BY ANOTHER POPULATION IN THE";
7860 PRINT#1,"BE GOVERNED BY ANOTHER POPULATION IN THE"
7870 PRINT"ECOSYSTEM?"
7880 PRINT#1,"ECOSYSTEM?"
7890 INPUT"CAN YOU GIVE ME AN ANSWER?"; IU$
7900 PRINT#1,"CAN YOU GIVE ME AN ANSWER ?"; IU$
7910 IF IU$="YES" THEN 8000
7920 IF IU$="NO" THEN 8020
7930 FOR AA=1 TO 10
7940 IF MID$(IU$ , AA, 7)<"FEEDING" THEN 7960
7950 GOTO7990
7960 NEXT AA
7970 PRINT"TRY AGAIN"; GOTO8000
7980 PRINT#1,"TRY AGAIN"; GOTO8000
7990 PRINT"BAD"; FORA=1 TO 1500; NEXTA: RETURN
8000 INPUT"TELL ME HOW"; IU$: GOTO7930
8010 PRINT#1,"TELL ME HOW ?"; IU$: GOTO7930
8020 PRINT"I AM SURE WITH A LITTLE THOUGHT YOU COULD DISCOVER THE REASON.
8030 PRINT#1,"I AM SURE WITH A LITTLE THOUGHT YOU COULD DISCOVER THE REASON.
8040 GOTO7970
8050 R:OK
8070 PRINT#1,"YOU DO NOT SEEM TO BELIEVE THAT THE
8080 PRINT"FISH FEED ON THE HERBIVORES."
8090 PRINT#1,"FISH FEED ON THE HERBIVORES."
8100 PRINT"PERHAPS THEY DON'T."
8110 PRINT#1,"PERHAPS THEY DON'T."
8120 PRINT"WHAT DO YOU NEED TO DO TO FIND OUT WHAT THE FISH EAT?"
8130 PRINT#1,"WHAT DO YOU NEED TO DO TO FIND OUT WHAT THE FISH EAT?"
8140 PRINT"WHY NOT REMOVE WHAT YOU THINK IS THE
8150 PRINT#1,"WHY NOT REMOVE WHAT YOU THINK IS THE
8160 PRINT"FOOD SOURCE FOR THE FISH, AND SEE WHAT
8170 PRINT#1,"FOOD SOURCE FOR THE FISH, AND SEE WHAT
8180 PRINT"HAPPENS."
8190 PRINT#1,"HAPPENS."
8200 PRINT"PRESS ANY KEY TO CONTINUE"
8210 GET IU$: IF IU$="THEN 8210
8220 RETURN
8230
8250 PRINT#1,"YOU DO NOT SEEM TO BELIEVE THAT THE
8260 PRINT"HERBIVORES FEED ON THE PLANKTON."
8270 PRINT#1,"HERBIVORES FEED ON THE PLANKTON."
8280 PRINT"PERHAPS THEY DON'T."
8290 PRINT#1, "PERHAPS THEY DON'T.
8300 PRINT"WHAT DO YOU NEED TO DO TO FIND OUT WHAT THE HERBIVORES EAT?
8310 PRINT#1, "WHAT DO YOU NEED TO DO TO FIND OUT WHAT THE HERBIVORES EAT?
8320 PRINT"WHY NOT REMOVE WHAT YOU THINK IS THE
8330 PRINT#1, "WHY NOT REMOVE WHAT YOU THINK IS THE
8340 PRINT"FOOD SOURCE FOR THE HERBIVORES, AND SEE
8350 PRINT#1, "FOOD SOURCE FOR THE HERBIVORES, AND SEE
8360 PRINT"WHAT HAPPENS.
8370 PRINT#1, "WHAT HAPPENS.
8380 PRINT"PRESS ANY KEY TO CONTINUE
8390 GETIU$: IF IU$ = "THEN8210
8400 RETURN
8410 PRINT"YOU HAVE SAID IN YOUR ANSWERS TO THE
8420 PRINT#1, "YOU HAVE SAID IN YOUR ANSWERS TO THE
8430 PRINT"QUESTIONS I HAVE JUST ASKED YOU, THAT
8440 PRINT#1, "QUESTIONS I HAVE JUST ASKED YOU, THAT
8450 PRINT"THE PHYTOPLANKTON DO NOT PHOTOSYNTHESISE
8460 PRINT#1, "THE PHYTOPLANKTON DO NOT PHOTOSYNTHESISE
8470 PRINT"CAN I ASK YOU WHAT YOU BELIEVE THE
8480 PRINT#1, "CAN I ASK YOU WHAT YOU BELIEVE THE
8490 PRINT"PHYTOPLANKTON TO BE?
8500 PRINT#1, "PHYTOPLANKTON TO BE?"
8510 INPUT"WHAT TYPE IN YOUR ANSWER PLEASE"; IU$
8520 PRINT#1, "WHAT TYPE IN YOUR ANSWER PLEASE"; IU$
8530 % = LEN(IU$)
8540 FOR WW = 1 TO X
8550 IF MID$(IU$, WW, 4) = "ALGA" THEN 8580
8560 NEXT WW
8570 GOTO8670
8580 PRINT"GOOD. I AGREE WITH YOU
8590 PRINT#1, "GOOD. I AGREE WITH YOU
8600 PRINT"NOW WHAT DO ALGAE DO TO GET THEIR FOOD?"
8610 PRINT#1, "NOW WHAT DO ALGAE DO TO GET THEIR FOOD?"
8620 PRINT"TRY AND SEE IF THE ALGAE FEED ON ANY OF
8630 PRINT#1, "TRY AND SEE IF THE ALGAE FEED ON ANY OF
8640 PRINT"THE OTHER POPULATIONS IN THE POND.
8650 PRINT#1, "THE OTHER POPULATIONS IN THE POND.
8660 GOTO8730
8670 PRINT"WHY NOT SUPPOSE THEY ARE A TYPE OF PLANT";
8680 PRINT#1, "WHY NOT SUPPOSE THEY ARE A TYPE OF PLANT";
8690 PRINT"AND SEE IF THEY CAN DO WITHOUT ANY OF
8700 PRINT#1, "AND SEE IF THEY CAN DO WITHOUT ANY OF
8710 PRINT "THE OTHER POPULATIONS IN THE POND?"
8720 PRINT#1, "THE OTHER POPULATIONS IN THE POND?"
8730 PRINT "DEPRESS ANY KEY TO CONTINUE"
8740 GOTO#1: IF IU=" " THEN 8740
8750 RETURN
8760
8780 PRINT#1, "IF PLANKTON PHOTOSYNTHETISE AS YOU HAVE
8790 PRINT "JUST SAID, WHAT WILL THEIR NUMBERS BE
8800 PRINT#1, "JUST SAID, WHAT WILL THEIR NUMBERS BE
8810 PRINT "GOVERNED BY?"
8820 PRINT#1, "GOVERNED BY?"
8830 PRINT "I SUGGEST THAT YOU TRY AN EXPERIMENT
8840 PRINT#1, "I SUGGEST THAT YOU TRY AN EXPERIMENT
8850 PRINT "WHICH WILL FOLLOW THE NUMBERS OF
8860 PRINT#1, "WHICH WILL FOLLOW THE NUMBERS OF
8870 PRINT "PLANKTON WITH VARYING TEMPERATURE AND
8880 PRINT#1, "PLANKTON WITH VARYING TEMPERATURE AND
8890 PRINT "LIGHT."
8900 PRINT#1, "LIGHT.
8910 PRINT "DEPRESS ANY KEY TO CONTINUE"
8920 GOTO#1: IF IU=" " THEN 8920
8930 RETURN
8940 PRINT#1, "IF THE PLANKTON NO'S ARE GOVERNED BY
8950 PRINT#1, "IF THE PLANKTON NO'S ARE GOVERNED BY
8960 PRINT "THE ENVIRONMENT, HERBIVORES FEED ON
8970 PRINT#1, "THE ENVIRONMENT, HERBIVORES FEED ON
8980 PRINT "PLANKTON, FISH FEED ON HERBIVORES,
8990 PRINT#1, "PLANKTON, FISH FEED ON HERBIVORES,
9000 PRINT "WON'T THE ENVIRONMENT AFFECT ALL OF
9010 PRINT#1, "WON'T THE ENVIRONMENT AFFECT ALL OF
9020 PRINT "THE POPULATIONS IN THE POND?"
9030 PRINT#1, "THE POPULATIONS IN THE POND?"
9040 PRINT "TRY AND SHOW THAT THE ENVIRONMENT DOES
9050 PRINT#1, "TRY AND SHOW THAT THE ENVIRONMENT DOES
9060 PRINT "NOT HAVE AN EFFECT ON THE POPULATIONS IN
9070 PRINT#1, "NOT HAVE AN EFFECT ON THE POPULATIONS IN
9080 PRINT "IN THE POND."
9090 PRINT#1, "IN THE POND."
9100 PRINT "DEPRESS ANY KEY TO CONTINUE"
9110 GETIUS: IFIUS"="THEN9110
9120 RETURN
9130 PRINT"TRY AND SHOW THAT THE HERBIVORES AND/OR
9140 PRINT"TRY AND SHOW THAT THE HERBIVORES AND/OR
9150 PRINT"THE FISH AFFECT THE NUMBERS OF PLANKTON
9160 PRINT"THE FISH AFFECT THE NUMBERS OF PLANKTON
9170 PRINT"IN THE POND.
9180 PRINT"IN THE POND.
9190 PRINT"PRESS ANY KEY TO CONTINUE
9200 GET IU$: IFIUS"="THEN9200
9210 RETURN
9220 PRINT"HAVE A LOOK AT THE NUMBERS OF THE
9230 PRINT"HAVE A LOOK AT THE NUMBERS OF THE
9240 PRINT"VARIOUS POPULATIONS IN THE POND.
9250 PRINT"VARIOUS POPULATIONS IN THE POND.
9260 PRINT"TRY AND PROVE TO YOURSELF THAT THE
9270 PRINT"TRY AND PROVE TO YOURSELF THAT THE
9280 PRINT"VARIOUS POPULATIONS DO NOT CHANGE IN
9290 PRINT"VARIOUS POPULATIONS DO NOT CHANGE IN
9300 PRINT"NUMBERS THROUGH AN ANNUAL CYCLE.
9310 PRINT"NUMBERS THROUGH AN ANNUAL CYCLE.
9320 PRINT"DO THIS BY OBSERVING THE POND FOR A
9330 PRINT"DO THIS BY OBSERVING THE POND FOR A
9340 PRINT"NUMBER OF YEARS.
9350 PRINT"NUMBER OF YEARS.
9360 PRINT"WHAT COULD BE CAUSING THE CHANGE IN
9370 PRINT"WHAT COULD BE CAUSING THE CHANGE IN
9380 PRINT"NUMBERS THAT YOU SHOULD SEE?
9390 PRINT"NUMBERS THAT YOU SHOULD SEE?
9400 PRINT"PRESS ANY KEY TO CONTINUE
9410 GET IU$: IFIUS"="THEN9410
9420 RETURN
9430 PRINT"HAVE A LOOK AT A POND AFTER YOU HAVE
9440 PRINT"HAVE A LOOK AT A POND AFTER YOU HAVE
9450 PRINT"SET IT UP WITH VARYING NUMBERS OF POND
9460 PRINT"SET IT UP WITH VARYING NUMBERS OF POND
9470 PRINT"ORGANISMS.  SHOW THAT THE POND
9480 PRINT"ORGANISMS.  SHOW THAT THE POND
9490 PRINT"ORGANISMS DO NOT EVER REACH A SET LEVEL
9500 PRINT#1,"ORGANISMS DO NOT EVER REACH A SET LEVEL-
9510 PRINT"OR EQUILIBRIUM WHICH IS THE SAME EVEN-
9520 PRINT#1,"OR EQUILIBRIUM WHICH IS THE SAME EVEN-
9530 PRINT"WITH THE EXPERIMENTS STARTING WITH-
9540 PRINT#1,"WITH THE EXPERIMENTS STARTING WITH-
9550 PRINT"DIFFERENT NUMBERS OF THE POND ORGANISMS-
9560 PRINT#1,"DIFFERENT NUMBERS OF THE POND ORGANISMS-
9570 PRINT"PRESS ANY KEY TO CONTINUE
9580 GET IU$ : IF IU$ ="THEN9580
9590 RETURN
9600 PRINT":"NOW THAT YOU HAVE REALISED THAT THE-
9610 PRINT#1,"NOW THAT YOU HAVE REALISED THAT THE-
9620 PRINT"POND ORGANISMS CAN REACH AN EQUILIBRIUM-
9630 PRINT#1,"POND ORGANISMS CAN REACH AN EQUILIBRIUM-
9640 PRINT"OF NUMBERS, SHOW BY SETTING UP AN-
9650 PRINT#1,"OF NUMBERS, SHOW BY SETTING UP AN-
9660 PRINT"EXPERIMENT IN MODE 3 OF THE PROGRAMME-
9670 PRINT#1,"EXPERIMENT IN MODE 3 OF THE PROGRAMME-
9680 PRINT"THAT FISHING DOES NOT UPSET THE-
9690 PRINT#1,"THAT FISHING DOES NOT UPSET THE-
9700 PRINT"EQUILIBRIUM OF THE NUMBERS OF EACH OF-
9710 PRINT#1,"EQUILIBRIUM OF THE NUMBERS OF EACH OF-
9720 PRINT"THESE ORGANISMS-
9730 PRINT#1,"THESE ORGANISMS-
9740 PRINT"PRESS ANY KEY TO CONTINUE
9750 GET IU$ : IF IU$ ="THEN9750
9760 RETURN
9770 PRINT":"WHAT DO YOU THINK THE NUMBER OF FISH-
9780 PRINT#1,"WHAT DO YOU THINK THE NUMBER OF FISH-
9790 PRINT"CAUGHT BY THE FISHERMEN WILL BE-
9800 PRINT#1,"CAUGHT BY THE FISHERMEN WILL BE-
9810 PRINT"PROPORTIONAL TO?
9820 PRINT#1,"PROPORTIONAL TO?
9830 PRINT"TRY SETTING UP AN EXPERIMENT WHICH WILL-
9840 PRINT#1,"TRY SETTING UP AN EXPERIMENT WHICH WILL-
9850 PRINT"SHOW THAT THE FISHING RATE (NUMBER OF-
9860 PRINT#1,"SHOW THAT THE FISHING RATE (NUMBER OF-
9870 PRINT"FISHERMEN X NUMBER OF TIMES THE-
9880 PRINT#1,"FISHERMEN X NUMBER OF TIMES THE-
9080 PRINT"FISHERMEN FISH EACH MONTH) IS THE
9090 PRINT#1,"FISHERMEN FISH EACH MONTH) IS THE
9100 PRINT"DETERMINING FACTOR.
9110 PRINT#1,"DETERMINING FACTOR.
9120 PRINT"WHAT ELSE COULD AFFECT THE NUMBER OF FISH CAUGHT?
9130 PRINT#1,"WHAT ELSE COULD AFFECT THE NUMBER OF FISH CAUGHT?
9140 PRINT"PRESS ANY KEY TO CONTINUE
9150 GETIUS:IFIUS=""THEN9960
9160 RETURN
9170 PRINT"YOU HAVE REALISED THAT THE
9180 PRINT#1,"YOU HAVE REALISED THAT THE
9190 PRINT"POND ORGANISMS CAN REACH AN EQUILIBRIUM
9200 PRINT#1,"POND ORGANISMS CAN REACH AN EQUILIBRIUM
9210 PRINT"OF NUMBERS, SHOW BY SETTING UP AN
9220 PRINT#1,"OF NUMBERS, SHOW BY SETTING UP AN
9230 PRINT"EXPERIMENT IN MODE 4 OF THE PROGRAMME.
9240 PRINT#1,"EXPERIMENT IN MODE 4 OF THE PROGRAMME,
9250 PRINT"THAT POLLUTION DOES NOT UPSET THE
9260 PRINT#1,"THAT POLLUTION DOES NOT UPSET THE
9270 PRINT"EQUILIBRIUM OF THE NUMBERS OF EACH OF
9280 PRINT#1,"EQUILIBRIUM OF THE NUMBERS OF EACH OF
9290 PRINT"THESE ORGANISMS.
9300 PRINT#1,"THESE ORGANISMS.
9310 PRINT"PRESS ANY KEY TO CONTINUE
9320 GETIUS:IFIUS=""THEN9130
9330 RETURN
20000 DOPEN#4,"RESULTS",L10,D1
20010 NA=NA+1
20020 RECORD#4,(NA):PRINT#4,FF9
20030 NA=NA+1
20040 RECORD#4,(NA):PRINT#4,HH9
20050 NA=NA+1
20060 RECORD#4,(NA):PRINT#4,XX9
20070 NA=NA+1
20080 RECORD#4,(NA):PRINT#4,BB7
20090 DCLOSE#4
20100 RETURN
Appendix 12b

The Determination of Level of Understanding
of those using POND2HELP

The determination of the L.O.U. starts by the computer selecting any one of the twenty one questions by random. The student is then asked to say whether this statement is true ("Y") or false ("N"). If the answer given by the student is correct, a question of higher L.O.U. is chosen by a process of bifurcation. In other words, a question which is half-way between the L.O.U. and the highest L.O.U. is chosen. If this is, again answered correctly then the process is repeated. Whenever a question is going to be asked for a second time, the program refuses to do so and returns to the main part of the program, the L.O.U. being determined at this point. However, if a question is answered incorrectly, a question at a lower L.O.U. is chosen, again by a process of bifurcation, either between the highest L.O.U. at which a question has been answered correctly, or the lowest L.O.U.

By determining where a student is according to this linear hierarchy it is hoped that suitable guidance can be provided whenever requested. However, the guidance is not provided solely on a currently determined L.O.U. but also on the past record of L.O.Us.

After a student has provided answers to the questions from which his/her L.O.U. is determined, s/he is given the chance to ask for help or guidance in how they should use the program to their best advantage. I have not allowed this assistance to be provided immediately on using the program, but only after three sets of questions have been answered. This is because I feel that the students should be allowed and
encouraged to decide how to use the program, and what the program has
to offer the student in terms of increasing their understanding of the
simulation model. It will, hopefully, increase the level of
confidence in those students who come to the computer with a feeling of
apprehension. However, it is not too long a period for the students
to work without any form of guidance.

The level of guidance offered to the students is determined from past
determinations of their L.O.U. after each decision "not to continue" as
previously described. It requires the calculation of their mean
L.O.U., their highest L.O.U., and their currently held L.O.U. The
currently held L.O.U. is compared with their mean L.O.U. and their
highest L.O.U.

If the current L.O.U. is less than the mean L.O.U. then the level of
guidance is set at the same level as their mean L.O.U. This should
prove to be sufficiently higher than that presently held, without
attempting to provide assistance at a level too far removed from what
appears to be their misconceptions of the simulation model. Otherwise
the level of significance is set at one level higher than the mean
level of understanding.
APPENDIX 13a

FLOW-CHARTS FOR THE DETERMINATION OF THE LEVEL OF UNDERSTANDING OF THOSE USING POND2HELP
INTRODUCTORY INFORMATION

RANDOM SELECTION OF QUESTION FROM DISK FILE

PRINT QUESTION IN A BOX ON VDU

CHECK IF IS & HASN'T USED PROGRAM

IF IS & HAS USED PROGRAM

STUDENT INPUTS REPLY TO QUESTION

INCORRECT

SELECT A HARDER QUESTION BY BIFURCATION

SELECT AN EASIER QUESTION BY BIFURCATION

CHECK TO SEE IF QUESTION HAS NOT BEEN ASKED IN CURRENT SERIES

NO

IF HAS & HAS NOT USED PROGRAM

A

(appendix 13a)
STORE LAST QUESTION ANSWERED CORRECTLY ON A DISK FILE

CHOOSE MODE OF PROGRAM

SETS UP ECOSYSTEM MODEL ACCORDING TO INPUT VALUES

DATA OUTPUT (GRAPH OR TABLE)

CONT. WITH PRESENT VALUES IN CURRENT MODE

B

C

STORE LAST QUESTION ANSWERED CORRECTLY ON A DISK FILE

REQUIRE GUIDANCE?

D

E

NO

YES

NO

YES

(appendix 13a)
FIND THE L.O.U. FOR EACH SERIES OF QUESTIONS ASKED-RETRIEVED FROM DISK

FIND CURRENT, HIGHEST & MEAN L.O.U.
SET MA TO 0

IS CURRENT L.O.U. < MEAN L.O.U.? NO
YES
SET GUIDANCE LEVEL AT INT(MEAN*0.5)

IS CURRENT L.O.U. = MEAN L.O.U.? NO
YES
SET GUIDANCE LEVEL AT INT(MEAN*1.5)

YES
SET GUIDANCE LEVEL AT CURRENT L.O.U. + 1

PRINT GUIDANCE ON V.D.U.

SET COUNTER TO MA = MA + 1

IS MA = 1?
NO
YES
SET GUIDANCE LEVEL TO 1 HIGHER THAN BEFORE

WANT ANY MORE GUIDANCE?
NO
YES
E

(appendix 13a)
Appendix 13b

Help Provided, on request, to students using POND2HELP

Level 1

I suggest that you have another look at the top of the table for the multiplication factors of the plankton, herbivores and fish, and then reconsider the relative sizes of each of the populations in the pond.

Level 2

You have said that the populations in the pond are not interdependent. In other words, that the change in size of one population will not affect any of the other populations in the pond. Although I am not disagreeing with you nor am I agreeing with you, I would like to suggest that you try to see whether you are correct.

To do this I want you to suppose that the populations are interdependent, and design and run an experiment which will prove or disapprove this supposition. Perhaps you could do this by removing a population from the pond.

Level 3

You have said that the fish are not proportional to the herbivores, and the fish are proportional to the herbivores and plankton. Can I suggest that you try and vary the population sizes to see whether the fish respond/do not respond to these changes.
Level 4

You have said that the herbivores are not proportional to the plankton. It might be fruitful for you to investigate this matter a little more. How would you see whether the herbivores were proportional to the plankton. What would you vary? Plankton. O.K. Try it.

Level 5

Having realised that the fish are proportional to the herbivores, and the herbivores are proportional to the plankton, I think perhaps you should vary one of these populations to see its effect on the other two populations. Consider carefully which of the populations you should vary.

Level 6

So far you appear to have realised that the populations in the pond are interdependent. You appear to have realised also that the fish are proportional to the herbivores, and that the herbivores are proportional to the plankton. You also believe that the fish feed on the herbivores and the herbivores feed on plankton.

Why not try looking at how this interdependence of populations you have indicated that you believe to exist might actually take place.

How might the size of the populations be governed by another population in the ecosystem?
Level 7
You do not seem to believe that the fish feed on the herbivores. Perhaps they don't. What do you need to do to find out what the fish eat? Why not remove what you think is the source of food for the fish, and see what happens.

Level 8
You do not seem to believe that the herbivores feed on the plankton. Perhaps they don't. What do you need to do to find out what the herbivores eat? Why not remove what you think is the food source for the herbivores and see what happens.

Level 9
You have said in your answers to the questions I have just asked you, that the phytoplankton do not photosynthesise. Can I ask you what you believe the phytoplankton to be? Type in your answer please. (if answer is "algae" then continues)
Good. I agree with you.
Now what do algae do to get their food?
Try and see if the algae feed on any of the other populations in the pond.

Level 10
If plankton photosynthesise as you have just said, what will their numbers be governed by?
I suggest that you try an experiment which will follow the numbers of plankton with varying temperature and light.
Level 11
If the plankton numbers are governed by the environment, herbivores feed on plankton, fish feed on herbivores, wouldn't the environment affect all of the populations in the pond?
Try and show that the environment does not have an effect on the populations in the pond.

Level 12
Try and show that the herbivores and/or the fish affect the numbers of plankton in the pond.

Level 13
Have a look at the numbers of the various populations in the pond. Try and prove to yourself that the various populations do not change in numbers through an annual cycle. Do this by observing the pond for a number of years.

What could be causing the change in numbers that you should see?

Level 14
Have a look at a pond after you have set it up with varying numbers of pond organisms. Show that the pond organisms do not ever reach a set level or equilibrium which is the same even with the experiments starting with different numbers of the pond organisms.
Level 15

Now that you have realised that the pond organisms can reach an equilibrium of numbers, show by setting up an experiment in mode 3 of the programme, that fishing does not upset the equilibrium of the numbers of each of these organisms.

Level 16

What do you think the number of fish caught by the fishermen will be proportional to?

Try setting up an experiment which will show that the fishing rate (number of fishermen x number of times the fishermen fish each month) is the determining factor.

What else could affect the number of fish caught?

Level 17

Now that you have realised that the pond organisms can reach an equilibrium of numbers, show by setting up an experiment in mode 4 of the programme, that pollution does not upset the equilibrium of the numbers of each of these organisms.
Main points of the POND programs as perceived by the students

a. Taught nothing
b. Stable ecosystem
c. Populations in the ecosystem are interdependent
h. Numbers in a pond ecosystem vary
i. Statement of populations sizes
f. Trophic levels of ecosystem shown
s. Food pyramid mentioned
u. Plankton photosynthesise
t. Plankton are the essential organisms in the pond
g. "Factors" affect the ecosystem's equilibrium
r. Weather affects the ecosystem's equilibrium
d. Fishing affects the ecosystem's equilibrium
k. Different rates of catching fish, herbivores and plankton shown
q. Need to conserve fish numbers
e. Pollution affects the ecosystem
j. The effect of different pollution rates is shown
p. Man can affect the ecosystem
l. To compare/alter statistics
m. To obtain best financial gain
v. Financial gain is related to conservation of fish numbers
n. Forward planning
o. Problem-solving
w. Use of graphs/tables
APPENDIX 15

DATA PRESENTATION QUESTIONNAIRE
is questionnaire is concerned with the ways in which GCE A/L students prefer
tious kinds of numerical data to be presented. The data which I obtain
om the returned questionnaires will be used for a research programme
ncerned with student learning in science. The results, if at all useful,
y be given to your lecturers. The results might thus be of use in the
ys your teachers present information to you or other students. I would thus
preciate your cooperation in answering the questions below in a frank and
tailed way.
will preserve your anonymity. Names will not be disclosed in any report
at might be produced. However, by writing your name on the questionnaire
can contact you if I find that it proves necessary.
anks for co-operation.
.J.Dicker (Senior Lecturer in Biology)
tober 1982

our name

Male / Female (delete inappropriate sex description)

year of A/L course 1st 2nd Revision (ring appropriate year)

lease tick the A/L subjects that you are presently studying:

<table>
<thead>
<tr>
<th>Physics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td></td>
</tr>
<tr>
<td>Statistics</td>
<td></td>
</tr>
<tr>
<td>Computing Science</td>
<td></td>
</tr>
<tr>
<td>Chemistry</td>
<td></td>
</tr>
<tr>
<td>Botany</td>
<td></td>
</tr>
<tr>
<td>Zoology</td>
<td></td>
</tr>
<tr>
<td>Biology</td>
<td></td>
</tr>
</tbody>
</table>

***************
WHEN COMPLETED PLEASE RETURN TO YOUR A/L LECTURERS OR TO ME*********
Figure 1

<table>
<thead>
<tr>
<th>Time (mins)</th>
<th>No. Bacterial cells/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>60</td>
<td>324</td>
</tr>
<tr>
<td>120</td>
<td>1,051</td>
</tr>
<tr>
<td>180</td>
<td>3,406</td>
</tr>
<tr>
<td>240</td>
<td>11,042</td>
</tr>
<tr>
<td>300</td>
<td>35,796</td>
</tr>
<tr>
<td>360</td>
<td>116,038</td>
</tr>
<tr>
<td>420</td>
<td>376,155</td>
</tr>
<tr>
<td>480</td>
<td>478,277</td>
</tr>
<tr>
<td>540</td>
<td>578,743</td>
</tr>
<tr>
<td>600</td>
<td>668,130</td>
</tr>
</tbody>
</table>

Figure 2

Figure 3

Figure 4
Please indicate in the series of boxes below which of each of the two presentations indicated you prefer:

<table>
<thead>
<tr>
<th></th>
<th>Figure 1 (A) or Figure 2 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why?

<table>
<thead>
<tr>
<th></th>
<th>Figure 1 (A) or Figure 3 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why?

<table>
<thead>
<tr>
<th></th>
<th>Figure 1 (A) or Figure 4 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why?

<table>
<thead>
<tr>
<th></th>
<th>Figure 2 (A) or Figure 3 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why?

<table>
<thead>
<tr>
<th></th>
<th>Figure 3 (A) or Figure 4 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Why?

|   | Are figures 1, 2, 3 and 4 representations of the same numerical data? |
|---|---------------------------------------------------------------|---|
| 6 | YES                                                           |   |
|   | NO                                                            |   |

Which, if any, are different from the rest?
Figure 5

<table>
<thead>
<tr>
<th>Month</th>
<th>Phytoplankton no's (x 10^9)</th>
<th>Herbivore no's (x 10^6)</th>
<th>Fish no's (actual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>115</td>
<td>24</td>
<td>942</td>
</tr>
<tr>
<td>Feb</td>
<td>258</td>
<td>34</td>
<td>745</td>
</tr>
<tr>
<td>March</td>
<td>362</td>
<td>50</td>
<td>675</td>
</tr>
<tr>
<td>April</td>
<td>332</td>
<td>55</td>
<td>1680</td>
</tr>
<tr>
<td>May</td>
<td>319</td>
<td>63</td>
<td>3580</td>
</tr>
<tr>
<td>June</td>
<td>301</td>
<td>58</td>
<td>3350</td>
</tr>
<tr>
<td>July</td>
<td>316</td>
<td>46</td>
<td>2497</td>
</tr>
<tr>
<td>Aug</td>
<td>269</td>
<td>52</td>
<td>2037</td>
</tr>
<tr>
<td>Sept</td>
<td>253</td>
<td>37</td>
<td>1570</td>
</tr>
<tr>
<td>Oct</td>
<td>176</td>
<td>35</td>
<td>1394</td>
</tr>
<tr>
<td>Nov</td>
<td>140</td>
<td>33</td>
<td>1241</td>
</tr>
<tr>
<td>Dec</td>
<td>111</td>
<td>28</td>
<td>1184</td>
</tr>
</tbody>
</table>

Figure 6

Phytoplankton (x 1,000,000,000)

Herbivores (x 100,000)

Fish (actual no)

- 588 -
indicate in the series of boxes below which of each of the presentations indicated you prefer, and why:

<table>
<thead>
<tr>
<th>Figure 5 (A) or Figure 6 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure 5 (A) or Figure 7 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure 5 (A) or Figure 8 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure 6 (A) or Figure 7 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure 7 (A) or Figure 8 (B)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Why?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Are figures 5, 6, 7 and 8 representations of the same numerical data?

Which, if any, are different from the rest?
Figures 2 and 7 are examples of a LOW RESOLUTION GRAPH produced on a computer.
Figures 3 and 8 are examples of a HIGH RESOLUTION GRAPH produced on a computer.

In the three scales below, I would like you to place tables (T), low resolution graphs (L) and high resolution graphs (H) according to how you rate each of their usefulness to the following people:-

1. **TO A MATHEMATICIAN/PHYSICIST**

Not at all

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

Why? ........................................................................................................................................
........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

2. **TO A BIOLOGIST**

Not at all

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

Why? ........................................................................................................................................
........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

3. **TO YOU**

Not at all

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

Why? ........................................................................................................................................
........................................................................................................................................
........................................................................................................................................
........................................................................................................................................

-----------------------------------------------------------------------------------------------------------------------------------

Thanks for taking the time to complete this questionnaire, can you now please ensure that it is returned to me.
APPENDIX 16
ORDER OF CONCEPT ACQUISITION FOR THE STUDENTS USING
USING THE POND PROGRAMS

Program: POND-2

<table>
<thead>
<tr>
<th>Student's Initials</th>
<th>List of Concepts in Order Acquired</th>
</tr>
</thead>
<tbody>
<tr>
<td>DW 18 19 20 21 1 30 7 9 4 22 5 10 8 6</td>
<td></td>
</tr>
<tr>
<td>GU 20 6 7 9 21</td>
<td></td>
</tr>
<tr>
<td>ST 7 31 6 32 33 10</td>
<td></td>
</tr>
<tr>
<td>PS 34 7 31 21 35 36 22 20 37</td>
<td></td>
</tr>
<tr>
<td>SHL 18 14 15 21</td>
<td></td>
</tr>
<tr>
<td>NP 21 37 23 15 16 7 9</td>
<td></td>
</tr>
<tr>
<td>TS 14 31 6 20 5 21 7 10 38</td>
<td></td>
</tr>
<tr>
<td>PN 1 7 39 9 11 18 21</td>
<td></td>
</tr>
<tr>
<td>MW 37 1 22 21 15 8 4 18 40</td>
<td></td>
</tr>
</tbody>
</table>

Program: PONDQU

<table>
<thead>
<tr>
<th>Student's Initials</th>
<th>List of Concepts in Order Acquired</th>
</tr>
</thead>
<tbody>
<tr>
<td>JB 41 42</td>
<td></td>
</tr>
<tr>
<td>CP 9 29 6 25 26 8 7 21</td>
<td></td>
</tr>
<tr>
<td>SA 9 27</td>
<td></td>
</tr>
<tr>
<td>SW 11 7 9 1 21 22</td>
<td></td>
</tr>
<tr>
<td>AB 20 25 26 9 7 28 8 18 19 21</td>
<td></td>
</tr>
<tr>
<td>AR 19 7</td>
<td></td>
</tr>
<tr>
<td>RR 35</td>
<td></td>
</tr>
<tr>
<td>SH2 31 7 37</td>
<td></td>
</tr>
<tr>
<td>JHL 20</td>
<td></td>
</tr>
</tbody>
</table>
Program: PONDGAME

<table>
<thead>
<tr>
<th>Student's Initials</th>
<th>List of Concepts in Order Acquired</th>
</tr>
</thead>
<tbody>
<tr>
<td>JH2</td>
<td>31 7 43 44</td>
</tr>
<tr>
<td>AY</td>
<td>31 7 9 11 10</td>
</tr>
<tr>
<td>AM</td>
<td>7 9 15 14</td>
</tr>
<tr>
<td>RC1</td>
<td>20 14 9 10</td>
</tr>
<tr>
<td>SE</td>
<td>9</td>
</tr>
<tr>
<td>CH</td>
<td>13 9 21</td>
</tr>
<tr>
<td>HS</td>
<td>9 21</td>
</tr>
</tbody>
</table>

Program: POND2HELP

<table>
<thead>
<tr>
<th>Student's Initials</th>
<th>List of Concepts in Order Acquired</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>46 7 6 13 14 20 26 8 31</td>
</tr>
<tr>
<td>SDT</td>
<td>1</td>
</tr>
<tr>
<td>FQ</td>
<td>34 18 7 9</td>
</tr>
<tr>
<td>DG</td>
<td>47 22 21 13 23 16</td>
</tr>
<tr>
<td>SB</td>
<td>20 7 9 13 14 31</td>
</tr>
<tr>
<td>RC2</td>
<td>15/16 31</td>
</tr>
<tr>
<td>DC</td>
<td>7 9 8 10 24 18 22 15 23</td>
</tr>
<tr>
<td>PP</td>
<td>-</td>
</tr>
<tr>
<td>DH</td>
<td>31</td>
</tr>
</tbody>
</table>
## APPENDIX 17

### LIST OF CONCEPTS DEMONSTRATED BY STUDENTS USING THE POND PROGRAMS

<table>
<thead>
<tr>
<th>Concept Number</th>
<th>Concept Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Organisms are interdependent in an ecosystem</td>
</tr>
<tr>
<td>2</td>
<td>Interdependence is reflected by feeding habits</td>
</tr>
<tr>
<td>3</td>
<td>All communities depend on the sun</td>
</tr>
<tr>
<td>4</td>
<td>Primary producers &quot;trap&quot; solar energy</td>
</tr>
<tr>
<td>5</td>
<td>Plankton can exist without herbivores and fish</td>
</tr>
<tr>
<td>6</td>
<td>Plankton numbers are largely controlled by the physical environment</td>
</tr>
<tr>
<td>7</td>
<td>Herbivores are dependent on the phytoplankton</td>
</tr>
<tr>
<td>8</td>
<td>Herbivores are preyed upon by the fish</td>
</tr>
<tr>
<td>9</td>
<td>Fish are dependent on the herbivores</td>
</tr>
<tr>
<td>10</td>
<td>The phytoplankton are preyed upon by the herbivores</td>
</tr>
<tr>
<td>11</td>
<td>Plankton numbers &gt; herbivore numbers &gt; fish numbers</td>
</tr>
<tr>
<td>12</td>
<td>Fish are preyed upon by the fishermen</td>
</tr>
<tr>
<td>13</td>
<td>The number of fish caught is dependent on the no. of fish</td>
</tr>
<tr>
<td>14</td>
<td>The number of fish caught is dependent on the fishing rate</td>
</tr>
<tr>
<td>15</td>
<td>Pollution leads to a decline in the fish numbers</td>
</tr>
<tr>
<td>16</td>
<td>Pollution leads to a decline in herbivore numbers</td>
</tr>
<tr>
<td>17</td>
<td>Low and moderate pollution levels can lead to an increase in phytoplankton numbers</td>
</tr>
<tr>
<td>18</td>
<td>A balance between populations can be achieved</td>
</tr>
<tr>
<td>19</td>
<td>Even with a balance, numbers can change cyclically</td>
</tr>
</tbody>
</table>
Weather causes cyclical changes in numbers/affects the ecosystem

Fishing causes the fish numbers to decrease

All communities are dependent on the phytoplankton

Pollution helps the phytoplankton to grow

Fishing upsets the balance of the ecosystem

Phytoplankton use oxygen in the water

Fish require oxygen - fish die due to a lack of oxygen

Phytoplankton are eaten by higher animals

Phytoplankton feed on algae

Phytoplankton numbers are not proportional to the herbivore numbers

Phytoplankton feed on fish excreta

Fish feed on the phytoplankton

Phytoplankton increase in pollution because they take up nitrogen and oxygen

Fish and herbivores decrease in pollution because the phytoplankton take up nitrogen and oxygen

Phytoplankton vary with fish numbers

Fishing causes the phytoplankton to decrease

Phytoplankton increase in pollution because the fish decrease and the oxygen concentration increases

Fish are dependent on the herbivores and phytoplankton

Herbivore numbers are controlled by the fish numbers

Fish and herbivore numbers are not related

Phytoplankton numbers are proportional to the herbivore numbers

Phytoplankton numbers < herbivore numbers < fish numbers

Fish compete with phytoplankton for food
Phytoplankton and herbivores are the only organisms that can live together.

There is a control system whereby the organisms reproduce faster when they are predated.

Phytoplankton and herbivores eat fish.

Herbivore numbers are not dependent on fish numbers.

Phytoplankton are dependent on the fish and herbivores.
Appendix 18a
Frequency of demonstration of cognitive activities by those using the POND-2

<table>
<thead>
<tr>
<th>Cognitive activity.</th>
<th>DW</th>
<th>ST</th>
<th>PS</th>
<th>SH</th>
<th>NP</th>
<th>TS</th>
<th>PN</th>
<th>MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Concepts at start (list A)</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2. Concepts at start (list B)</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>3. Number of INPUTs</td>
<td>11</td>
<td>14</td>
<td>32</td>
<td>23</td>
<td>16</td>
<td>28</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>4. Number of Actions taken</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>16</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>5. Number of Observations</td>
<td>8</td>
<td>23</td>
<td>52</td>
<td>8</td>
<td>55</td>
<td>89</td>
<td>32</td>
<td>110</td>
</tr>
<tr>
<td>6. Number of valid concepts formed</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>10</td>
<td>11</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>7. Number invalid concepts formed</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>8. Total Number concepts formed</td>
<td>7</td>
<td>13</td>
<td>9</td>
<td>3</td>
<td>11</td>
<td>16</td>
<td>7</td>
<td>31</td>
</tr>
<tr>
<td>9. Number predictions (by extrapolation)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>10. Number of &quot;selection of appropriate enquiry skills&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11. Number predictions</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>12. Number theory-laden observations (ex.1)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>13. Number theory-laden observations (ex.2)</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14. Number hypothesis testing activities (ex.1)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>15. Number hypothesis testing activities (ex.2)</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>16. Number hypothesis testing activities (ex.3)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>17. Number concepts acquired from other concepts</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18. Number dialectic activities</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>19. Number concepts at finish (list B)</td>
<td>7</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
### Appendix 18b
Frequency of demonstration of cognitive activities by those using the PONDQU

<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>Student's initials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JB</td>
</tr>
<tr>
<td>1. Concepts at start (list A)</td>
<td>0</td>
</tr>
<tr>
<td>2. Concepts at start (list B)</td>
<td>0</td>
</tr>
<tr>
<td>3. Number of INPUTs</td>
<td>9</td>
</tr>
<tr>
<td>4. Number of Actions taken</td>
<td>0</td>
</tr>
<tr>
<td>5. Number of Observations</td>
<td>4</td>
</tr>
<tr>
<td>6. Number of valid concepts formed</td>
<td>0</td>
</tr>
<tr>
<td>7. Number invalid concepts formed</td>
<td>2</td>
</tr>
<tr>
<td>8. Total Number concepts formed</td>
<td>2</td>
</tr>
<tr>
<td>9. Number predictions (by extrapolation)</td>
<td>0</td>
</tr>
<tr>
<td>10. Number of &quot;selection of appropriate enquiry skills&quot;</td>
<td>0</td>
</tr>
<tr>
<td>11. Number predictions</td>
<td>0</td>
</tr>
<tr>
<td>12. Number theory-laden observations (ex.1)</td>
<td>0</td>
</tr>
<tr>
<td>13. Number theory-laden observations (ex.2)</td>
<td>0</td>
</tr>
<tr>
<td>14. Number hypothesis testing activities (ex.1)</td>
<td>0</td>
</tr>
<tr>
<td>15. Number hypothesis testing activities (ex.2)</td>
<td>0</td>
</tr>
<tr>
<td>16. Number hypothesis testing activities (ex.3)</td>
<td>0</td>
</tr>
<tr>
<td>17. Number concepts acquired from other concepts</td>
<td>0</td>
</tr>
<tr>
<td>18. Number dialectic activities</td>
<td>0</td>
</tr>
<tr>
<td>19. Number concepts at finish (list B)</td>
<td>2</td>
</tr>
</tbody>
</table>
**Appendix 18c**

Frequency of demonstration of cognitive activities by those using the PONDGAME

<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>Student's initials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>JH2</td>
</tr>
<tr>
<td>1. Concepts at start (list A)</td>
<td>0</td>
</tr>
<tr>
<td>2. Concepts at start (list B)</td>
<td>0</td>
</tr>
<tr>
<td>3. Number of INPUT's</td>
<td>23</td>
</tr>
<tr>
<td>4. Number of Actions taken</td>
<td>1</td>
</tr>
<tr>
<td>5. Number of Observations</td>
<td>19</td>
</tr>
<tr>
<td>6. Number of valid concepts formed</td>
<td>2</td>
</tr>
<tr>
<td>7. Number invalid concepts formed</td>
<td>5</td>
</tr>
<tr>
<td>8. Total Number concepts formed</td>
<td>7</td>
</tr>
<tr>
<td>9. Number predictions (by extrapolation)</td>
<td>1</td>
</tr>
<tr>
<td>10. Number of &quot;selection of appropriate enquiry skills&quot;</td>
<td>0</td>
</tr>
<tr>
<td>11. Number predictions</td>
<td>1</td>
</tr>
<tr>
<td>12. Number theory-laden observations (ex.1)</td>
<td>0</td>
</tr>
<tr>
<td>13. Number theory-laden observations (ex.2)</td>
<td>0</td>
</tr>
<tr>
<td>14. Number hypothesis testing activities (ex.1)</td>
<td>0</td>
</tr>
<tr>
<td>15. Number hypothesis testing activities (ex.2)</td>
<td>1</td>
</tr>
<tr>
<td>16. Number hypothesis testing activities (ex.3)</td>
<td>0</td>
</tr>
<tr>
<td>17. Number concepts acquired from other concepts</td>
<td>0</td>
</tr>
<tr>
<td>18. Number dialectic activities</td>
<td>0</td>
</tr>
<tr>
<td>19. Number concepts at finish (list B)</td>
<td>4</td>
</tr>
</tbody>
</table>
Appendix 18d
Frequency of demonstration of cognitive activities by those using the POND2HELP

<table>
<thead>
<tr>
<th>Cognitive activity.</th>
<th>Student's initials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB SDT FQ DG SB RC2 DC PP NL DH</td>
</tr>
<tr>
<td>1. Concepts at start (list A)</td>
<td>1 0 1 2 2 2 2 1 2 4</td>
</tr>
<tr>
<td>2. Concepts at start (list B)</td>
<td>2 0 3 2 4 3 3 1 1 4</td>
</tr>
<tr>
<td>3. Number of INPUTs</td>
<td>21 7 9 10 30 23 5 9 14 12</td>
</tr>
<tr>
<td>4. Number of Actions taken</td>
<td>10 1 1 1 9 6 1 4 3 5</td>
</tr>
<tr>
<td>5. Number of Observations</td>
<td>101 36 64 31 80 52 20 56 53 52</td>
</tr>
<tr>
<td>6. Number of valid concepts formed</td>
<td>19 0 0 7 16 7 1 0 3 5</td>
</tr>
<tr>
<td>7. Number invalid concepts formed</td>
<td>0 1 3 5 3 4 0 2 5 0</td>
</tr>
<tr>
<td>8. Total Number concepts formed</td>
<td>19 1 3 12 19 11 1 2 8 5</td>
</tr>
<tr>
<td>9. Number predictions (by extrapolation)</td>
<td>3 0 0 4 0 1 0 0 0 0</td>
</tr>
<tr>
<td>10. Number of &quot;selection of appropriate enquiry skills&quot;</td>
<td>0 0 0 1 2 1 0 0 0 2</td>
</tr>
<tr>
<td>11. Number predictions</td>
<td>0 0 0 2 0 2 0 0 1 0</td>
</tr>
<tr>
<td>12. Number theory-laden observations (ex.1)</td>
<td>3 0 0 0 0 2 0 0 1 0</td>
</tr>
<tr>
<td>13. Number theory-laden observations (ex.2)</td>
<td>8 2 0 0 0 3 0 0 0 0</td>
</tr>
<tr>
<td>14. Number hypothesis testing activities (ex.1)</td>
<td>1 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>15. Number hypothesis testing activities (ex.2)</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>16. Number hypothesis testing activities (ex.3)</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>17. Number concepts acquired from other concepts</td>
<td>1 0 0 0 5 0 0 1 3 0</td>
</tr>
<tr>
<td>18. Number dialectic activities</td>
<td>0 0 0 5 2 3 0 0 3 0</td>
</tr>
<tr>
<td>19. Number concepts at finish (list B)</td>
<td>5 6 3 3 6 5 2 2 4 7</td>
</tr>
</tbody>
</table>
Appendix 19a
Correlations between cognitive activities for those using the POND-2

<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.9</td>
<td>-.51</td>
<td>.13</td>
<td>.08</td>
<td>.44</td>
<td>.11</td>
<td>.35</td>
<td>.14</td>
<td>-</td>
<td>.01</td>
<td>-.36</td>
<td>-.49</td>
<td>-.37</td>
<td>-.76</td>
<td>.28</td>
<td>.28</td>
<td>.54</td>
<td>.73</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-.25</td>
<td>.24</td>
<td>.31</td>
<td>.58</td>
<td>.31</td>
<td>.52</td>
<td>.15</td>
<td>-</td>
<td>-.02</td>
<td>-.17</td>
<td>.52</td>
<td>-.18</td>
<td>-.72</td>
<td>.5</td>
<td>.08</td>
<td>.8</td>
<td>.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.39</td>
<td>.74</td>
<td>.51</td>
<td>.7</td>
<td>.61</td>
<td>.27</td>
<td>-</td>
<td>.53</td>
<td>.38</td>
<td>.29</td>
<td>.26</td>
<td>.2</td>
<td>.61</td>
<td>-.31</td>
<td>.07</td>
<td>-.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.78</td>
<td>.66</td>
<td>.31</td>
<td>.57</td>
<td>.94</td>
<td>-</td>
<td>.45</td>
<td>-.38</td>
<td>-.43</td>
<td>-.15</td>
<td>-.09</td>
<td>.35</td>
<td>-.36</td>
<td>.23</td>
<td>.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.83</td>
<td>.79</td>
<td>.87</td>
<td>.68</td>
<td>-</td>
<td>.69</td>
<td>.14</td>
<td>-.09</td>
<td>.15</td>
<td>-.29</td>
<td>.68</td>
<td>-.26</td>
<td>.43</td>
<td>.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>.76</td>
<td>.97</td>
<td>.53</td>
<td>-</td>
<td>.54</td>
<td>-.2</td>
<td>-.36</td>
<td>-.27</td>
<td>-.39</td>
<td>.89</td>
<td>-.04</td>
<td>.53</td>
<td>.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.89</td>
<td>.18</td>
<td>-</td>
<td>.68</td>
<td>.28</td>
<td>.09</td>
<td>.31</td>
<td>.73</td>
<td>.2</td>
<td>.28</td>
<td>.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>.44</td>
<td>-</td>
<td>.62</td>
<td>-.04</td>
<td>.23</td>
<td>-.19</td>
<td>-.39</td>
<td>.89</td>
<td>.04</td>
<td>.48</td>
<td>.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>-</td>
<td>.56</td>
<td>-.36</td>
<td>-.36</td>
<td>-.06</td>
<td>-.15</td>
<td>.17</td>
<td>-.28</td>
<td>.15</td>
<td>.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Appendix 19b

**Correlations between cognitive activities for those using the PONDQU**

<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.94</td>
<td>.05</td>
<td>.38</td>
<td>.48</td>
<td>.16</td>
<td>-.05</td>
<td>.12</td>
<td>.02</td>
<td>-.13</td>
<td>.53</td>
<td>.37</td>
<td>.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>-.07</td>
<td>.43</td>
<td>.54</td>
<td>.32</td>
<td>-.03</td>
<td>.28</td>
<td>0</td>
<td>-.17</td>
<td>-.28</td>
<td>.43</td>
<td>.55</td>
<td>.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.02</td>
<td>.14</td>
<td>-.36</td>
<td>.16</td>
<td>-.25</td>
<td>.73</td>
<td>.45</td>
<td>.22</td>
<td>-.11</td>
<td>-.12</td>
<td>.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.82</td>
<td>.62</td>
<td>-.11</td>
<td>.52</td>
<td>.19</td>
<td>.11</td>
<td>.15</td>
<td>.44</td>
<td>.59</td>
<td>.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.64</td>
<td>.19</td>
<td>.68</td>
<td>.18</td>
<td>.22</td>
<td>.16</td>
<td>.34</td>
<td>.87</td>
<td>.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-.09</td>
<td>.88</td>
<td>-.19</td>
<td>.17</td>
<td>.36</td>
<td>-.03</td>
<td>.61</td>
<td>.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.4</td>
<td>.47</td>
<td>-.22</td>
<td>-.24</td>
<td>.44</td>
<td>.45</td>
<td>.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>-.4</td>
<td>.05</td>
<td>.22</td>
<td>.18</td>
<td>.77</td>
<td>.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.65</td>
<td>.43</td>
<td>-.32</td>
<td>-.23</td>
<td>.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>.94</td>
<td>-.25</td>
<td>-.18</td>
<td>.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>-.27</td>
<td>.19</td>
<td>.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>.35</td>
<td>.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.91</td>
<td>.47</td>
<td>.52</td>
<td>.32</td>
<td>.31</td>
<td>.61</td>
<td>.02</td>
<td>.08</td>
<td>.95</td>
<td>.44</td>
<td>.29</td>
<td>.06</td>
<td>.85</td>
<td>.63</td>
<td>.55</td>
<td>.55</td>
<td>.39</td>
<td>.32</td>
<td>.08</td>
</tr>
<tr>
<td>2</td>
<td>-.29</td>
<td>-.18</td>
<td>-.46</td>
<td>-.39</td>
<td>-.74</td>
<td>-.98</td>
<td>-.91</td>
<td>-.59</td>
<td>-.04</td>
<td>.55</td>
<td>-1.00</td>
<td>.63</td>
<td>.59</td>
<td>.55</td>
<td>.55</td>
<td>.39</td>
<td>.32</td>
<td>.08</td>
<td>.91</td>
</tr>
<tr>
<td>3</td>
<td>.32</td>
<td>.16</td>
<td>-.32</td>
<td>-.04</td>
<td>.03</td>
<td>.28</td>
<td>.77</td>
<td>.66</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
</tr>
<tr>
<td>4</td>
<td>.61</td>
<td>.16</td>
<td>.61</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
</tr>
<tr>
<td>5</td>
<td>.02</td>
<td>.91</td>
<td>.02</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
</tr>
<tr>
<td>6</td>
<td>.08</td>
<td>.32</td>
<td>.08</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
<td>.32</td>
</tr>
<tr>
<td>7</td>
<td>.95</td>
<td>.88</td>
<td>.95</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
</tr>
<tr>
<td>8</td>
<td>.44</td>
<td>.88</td>
<td>.44</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
</tr>
<tr>
<td>9</td>
<td>.29</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
<td>-.18</td>
</tr>
<tr>
<td>10</td>
<td>.06</td>
<td>.91</td>
<td>.06</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
<td>.91</td>
</tr>
<tr>
<td>11</td>
<td>.85</td>
<td>.04</td>
<td>.85</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
<td>.04</td>
</tr>
<tr>
<td>12</td>
<td>-.91</td>
<td>-.46</td>
<td>-.91</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
<td>-.46</td>
</tr>
<tr>
<td>13</td>
<td>-.32</td>
<td>-.27</td>
<td>-.32</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
<td>-.27</td>
</tr>
<tr>
<td>14</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
<td>.57</td>
</tr>
<tr>
<td>15</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
<td>.88</td>
</tr>
<tr>
<td>16</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
<td>.65</td>
</tr>
<tr>
<td>17</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
</tr>
<tr>
<td>19</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
<td>.48</td>
</tr>
</tbody>
</table>

Correlations between cognitive activities for those using the POMME
## Appendix 19d

Correlations between cognitive activities for those using the POND2HELP

<table>
<thead>
<tr>
<th>Cognitive activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.7</td>
<td>.17</td>
<td>.16</td>
<td>-.11</td>
<td>.13</td>
<td>-.01</td>
<td>.13</td>
<td>-.04</td>
<td>.72</td>
<td>.19</td>
<td>-.12</td>
<td>-.33</td>
<td>-.23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.43</td>
<td>.36</td>
<td>.2</td>
<td>.36</td>
<td>-.12</td>
<td>.32</td>
<td>-.08</td>
<td>.71</td>
<td>-.05</td>
<td>-.06</td>
<td>-.16</td>
<td>-.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.87</td>
<td>.7</td>
<td>.82</td>
<td>.22</td>
<td>.87</td>
<td>.13</td>
<td>.54</td>
<td>.16</td>
<td>.5</td>
<td>.37</td>
<td>.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.84</td>
<td>.87</td>
<td>-.19</td>
<td>.8</td>
<td>.16</td>
<td>.41</td>
<td>-.14</td>
<td>.62</td>
<td>.59</td>
<td>.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>.74</td>
<td>-.11</td>
<td>.69</td>
<td>.14</td>
<td>.11</td>
<td>-.3</td>
<td>.58</td>
<td>.6</td>
<td>.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>-.06</td>
<td>.96</td>
<td>.51</td>
<td>.41</td>
<td>.04</td>
<td>.6</td>
<td>.62</td>
<td>.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.23</td>
<td>.21</td>
<td>.08</td>
<td>.75</td>
<td>-.04</td>
<td>-.34</td>
<td>.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>.55</td>
<td>.42</td>
<td>.25</td>
<td>.57</td>
<td>.51</td>
<td>.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.02</td>
<td>.53</td>
<td>.43</td>
<td>.48</td>
<td>.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>.16</td>
<td>-.2</td>
<td>-.24</td>
<td>-.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>.24</td>
<td>-.03</td>
<td>-.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>.89</td>
<td>.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.21</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.07</td>
</tr>
</tbody>
</table>