STUDENTS' PERCEPTIONS AND LEARNING STYLES

ASSOCIATED WITH THE CONCEPT OF EVOLUTION BY NATURAL SELECTION

by

MARGARET N. BRUMBY

In partial fulfilment of the requirements of the Ph.D degree, University of Surrey, 1979.
SUMMARY

This project explored the understanding of evolution by natural selection, held by the whole first-year population of fifty-two students entering two courses in the Department of Human Biology and Health, at the University of Surrey.

A series of problems and tasks, containing both familiar and unfamiliar biological instances of the concepts under study were given in both written test format and during individual task interviews.

The results were analysed from three aspects:

(a) The conceptual understanding of three sub-ordinate concepts, natural selection, life, and time-scales associated with rates of change. This showed that although they had 'learnt' these concepts, only a minority of these students could use their knowledge and identify, and correctly apply these concepts to unfamiliar problems.

(b) Students' learning styles (defined as the way a task is perceived). These were categorized into analytic, holist and versatile for the series of biological tasks. Overall, half of the students were versatile, about 40% were classed as having consistently used an analytic style, and 10% used a holist style for these tasks. Variation in the results for three different tasks suggested that the style of the task itself may influence, to some degree, students' observed learning style.

(c) The ability of students to integrate new material into their existing knowledge (termed their level of integration). These were categorized into low and high, for both a familiar, and an unfamiliar biological task. Variation in the results between these two tasks suggested that levels of integration may be related to the content of the particular task.

Using the concept of natural selection as an instance of meaningful learning, it was found that the majority of students with sound understanding of this concept were students classed as versatile in their learning style, and showing a high level of integration. The implication of these findings to the development of conceptual learning in biological education is discussed.
ACKNOWLEDGMENTS

I wish to thank my supervisor, Dr. John Gilbert, for his careful and patient help throughout this project. Professor Lewis Elton, Professor John Clift, Dr. Malcolm Parlett, Dr. Peter Simpson, Dr. Eileen Oldfield and Dr. Diana Laurillard have freely offered critical advice during informal discussions. Mr. Mike Procter kindly helped with the statistical analysis in Stage 1.

I am indebted to Mrs. Sheila Mynard for her excellent advice about the presentation and her expert typing of the manuscript.

I am most grateful to the staff of the Department of Human Biology and Health, particularly to Mr. Clive Turner, for their interest throughout this project. The thoughtful introduction of this project to the students, my participation in Orientation week activities and my subsequent inclusion in the normal lecture timetable, resulted in almost 100% student participation in all stages of the project.

Most of all I thank the students for their enthusiasm and willing participation in all tasks. Their individuality and diversity, revealed in this project, highlight the dimensions of our ignorance of human learning.
<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>INDEX</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>Introduction to the project.</td>
<td>1</td>
</tr>
<tr>
<td>1.</td>
<td><strong>LITERATURE REVIEW</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.1 Early theories of learning associated</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>with problem-solving</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.2 Recent theories of learning and the</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>structuring of knowledge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.3 Research into concept understanding</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>1.4 Individual differences in student learning</td>
<td>29</td>
</tr>
<tr>
<td>2.</td>
<td><strong>RESEARCH DESIGN AND METHODOLOGY</strong></td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>2.1 The research questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.2 Methodology Stage 1 — Pilot studies</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>2.3 Student populations — Stage 1</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>2.4 Further research questions</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>2.5 Methodology Stage 2 — Students' perceptions of basic concepts</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>2.6 Methodology Stage 3 — Learning styles</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>2.7 Student population — Stages 2 and 3</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>2.8 Methods of analysis</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>2.9 Terminology used in project.</td>
<td>59</td>
</tr>
<tr>
<td>3.</td>
<td><strong>THE CONCEPT OF NATURAL SELECTION</strong></td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>3.1 Analysis of the pilot problems</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>3.2 The validity of two forms of assessment</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>questions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.3 The determination of the level of</td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>concept understanding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.4 Origin and nature of misunderstandings</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>3.5 Interview with students with sound</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>understanding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.6 Individual learning styles shown in</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>interviews</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.7 Summary</td>
<td>94</td>
</tr>
<tr>
<td>CHAPTER</td>
<td>INDEX</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>THE OKLAHOMA DINOSAUR PROBLEM</td>
<td></td>
</tr>
<tr>
<td>4.1</td>
<td>Development of the problem</td>
<td>96</td>
</tr>
<tr>
<td>4.2</td>
<td>Analysis of the problem</td>
<td>97</td>
</tr>
<tr>
<td>4.3</td>
<td>Method of data collection and analysis</td>
<td>98</td>
</tr>
<tr>
<td>4.4</td>
<td>Results</td>
<td>98</td>
</tr>
<tr>
<td>4.5</td>
<td>Discussion</td>
<td>103</td>
</tr>
<tr>
<td>4.6</td>
<td>Summary</td>
<td>104</td>
</tr>
</tbody>
</table>

**STAGE 2 MAIN STUDY. STUDENTS' PERCEPTIONS OF BIOLOGICAL CONCEPTS**

| 5.       | UNDERSTANDING THE CONCEPT OF EVOLUTION BY NATURAL SELECTION. |
| 5.1     | Analysis of the problems                   | 105 |
| 5.2     | Data collection and analysis               | 111 |
| 5.3     | Results of individual problems             | 112 |
| 5.4     | Overall level of understanding of this concept | 116 |
| 5.5     | Concepts identification question           | 117 |
| 5.6     | Discussion                                  | 119 |
| 5.7     | Summary                                    | 123 |

| 6.       | TOWARDS A DEFINITION OF LIFE               |
| 6.1     | Analysis of the problems                   | 124 |
| 6.2     | Results of individual problems             | 129 |
| 6.3     | Discussion                                  | 138 |
| 6.4     | Summary                                    | 140 |

<p>| 7.       | STUDENTS' PERCEPTIONS OF TIME-SCALES AND THE RATE OF CHANGE |
| 7.1     | The concept of time-scale                  | 141 |
| 7.2     | Analysis of the time-scales problems        | 144 |
| 7.3     | Discussion of time-scales                  | 149 |
| 7.4     | Global future predictions                  | 150 |
| 7.5     | Personal future predictions                | 154 |
| 7.6     | Students' perceptions of the older generation's attitude to change | 157 |
| 7.7     | Discussion                                  | 159 |
| 7.8     | Summary                                    | 160 |</p>
<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>INDEX</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>STAGE 3 MAIN STUDY. STUDENTS' LEARNING STYLES</td>
<td></td>
</tr>
<tr>
<td>8.1</td>
<td>Terminology</td>
<td>162</td>
</tr>
<tr>
<td>8.2</td>
<td>The first descriptive task — the Immunity task</td>
<td>166</td>
</tr>
<tr>
<td>8.3</td>
<td>The second descriptive task — the Graph task</td>
<td>180</td>
</tr>
<tr>
<td>8.4</td>
<td>Consistency of learning styles for two similar tasks</td>
<td>185</td>
</tr>
<tr>
<td>8.5</td>
<td>Comparison of levels of integration for two similar tasks</td>
<td>187</td>
</tr>
<tr>
<td>8.6</td>
<td>The hypothesis-testing task — the Rock problem</td>
<td>189</td>
</tr>
<tr>
<td>8.7</td>
<td>Other observations related to learning styles</td>
<td>194</td>
</tr>
<tr>
<td>8.8</td>
<td>Consistency of learning styles for several biological tasks</td>
<td>195</td>
</tr>
<tr>
<td>8.9</td>
<td>Overall analysis of learning styles and levels of integration shown by students</td>
<td>199</td>
</tr>
<tr>
<td>8.10</td>
<td>Discussion</td>
<td>200</td>
</tr>
<tr>
<td>8.11</td>
<td>Summary</td>
<td>204</td>
</tr>
<tr>
<td>9.</td>
<td>RELATIONSHIP BETWEEN LEARNING STYLE AND CONCEPT UNDERSTANDING</td>
<td></td>
</tr>
<tr>
<td>9.1</td>
<td>Identification of students with sound understanding of natural selection</td>
<td>206</td>
</tr>
<tr>
<td>9.2</td>
<td>Discussion of the relationship of conceptual learning to the structure of knowledge.</td>
<td>208</td>
</tr>
<tr>
<td>9.3</td>
<td>Summary</td>
<td>211</td>
</tr>
<tr>
<td>10.</td>
<td>THE ROLE OF LEARNING STYLE IN FORMS OF ASSESSMENT</td>
<td></td>
</tr>
<tr>
<td>10.1</td>
<td>The use of multiple-choice questions in problem-solving</td>
<td>212</td>
</tr>
<tr>
<td>10.2</td>
<td>Reasons for choice</td>
<td>214</td>
</tr>
<tr>
<td>10.3</td>
<td>The role of learning styles in examination essays</td>
<td>216</td>
</tr>
<tr>
<td>10.4</td>
<td>Content vs. style</td>
<td>219</td>
</tr>
<tr>
<td>10.5</td>
<td>Discussion</td>
<td>222</td>
</tr>
<tr>
<td>10.6</td>
<td>Summary</td>
<td>223</td>
</tr>
<tr>
<td>CHAPTER</td>
<td>INDEX</td>
<td>PAGE</td>
</tr>
<tr>
<td>----------</td>
<td>--------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>11</td>
<td>DISCUSSION: LEARNING FOR TOMORROW</td>
<td>224</td>
</tr>
<tr>
<td>REFERENCES</td>
<td></td>
<td>236</td>
</tr>
<tr>
<td>APPENDIX I</td>
<td>Australian HSC results, 1976</td>
<td>242</td>
</tr>
<tr>
<td>APPENDIX II</td>
<td>Concept map of evolution</td>
<td>243</td>
</tr>
<tr>
<td>APPENDIX III</td>
<td>Stage 1. Written test</td>
<td>244</td>
</tr>
<tr>
<td>APPENDIX IV</td>
<td>Stage 2. Written test</td>
<td>248</td>
</tr>
<tr>
<td>APPENDIX V</td>
<td>Stage 2. Task interview schedule</td>
<td>256</td>
</tr>
<tr>
<td>APPENDIX VI</td>
<td>Stage 3. Immunity task</td>
<td>261</td>
</tr>
<tr>
<td>APPENDIX VII</td>
<td>Stage 3. Graph task</td>
<td>262</td>
</tr>
</tbody>
</table>
'From the dawn of consciousness until 6th August 1945, man had to live with the prospect of his death as an individual; Since the day when the first atomic bomb outshone the sun over Hiroshima, he has had to live with the prospect of his extinction as a species.'

ARTHUR KOESTLER

JANUS 1978
PREFACE. INTRODUCTION TO THE PROJECT.

As a teacher of Biology and Environmental Science at senior secondary level in Australia, I have found that students often experienced difficulty in grasping the concept of natural selection, the fundamental concept of Darwinian evolution. Their 'intuitive' reasoning seemed to be almost 'Lamarckian' in character, for example they believed that man is gradually losing his toes and appendix because he is no longer using them, (to climb trees, or digest cellulose respectively). They were not purely 'Lamarckian' because they knew this was a very slow process, occurring over many generations. These students reasoned in terms of adaptation, but not of selection.

In 1976 I co-ordinated the marking of the major essay for the VUSEB Higher School Certificate Biology examination, in Victoria, Australia. The question described a real, but unfamiliar problem of evolution (Appendix I), and the essays (indicated by the results) revealed that the majority of senior school Victorian Biology students had an extremely poor understanding of the principles of Darwinian evolution.

I was intrigued by this problem, not only from the teaching aspect, but from a much more philosophical view, for I believe that it is the most important single concept that mankind must understand, if we are ever to achieve a human 'balance of nature', with the natural environment.

As the concept map of evolution (Appendix II) shows, a change in the environment is a key concept related to the selective process and consequently the re-direction of the pathway of evolution.

This thesis is an account of the studies undertaken to explore difficulties students have in learning about evolution by natural selection. I have selected key points on the concept map and used a problem-solving approach to investigate how students conceptualize the origin of the diversity of life that surrounds them. This revealed striking differences in the ways these students approached and participated in these tasks.
The simplest model of learning that I differentiated at the beginning of this project was:

\[
\text{Input} \rightarrow \text{learning process} \rightarrow \text{outcome}
\]

As work progressed I divided the learning process further into:

\[
\text{Input} \rightarrow \begin{array}{c}
\text{intellectual + existing skills} \\
\text{knowledge}
\end{array} \rightarrow \text{learning outcome}
\]

A commonly accepted criterion of learning (reviewed in 1.3 p.25) is the ability to transfer previously learned knowledge and concepts and to correctly apply them in unfamiliar problems of the same kind. Thus problem-solving has become a tool by which to study the learning process.

In problem-solving, the outcome, a solution to the problem, depends on all preceding components:

(a) the input — both the problem itself, and also how the student perceives the problem,
(b) the process — the integration of skills, abilities and experience which collectively make up complex human thought.

The findings described in this thesis, using complex biological problems and tertiary biology students, may have wider application to our understanding of learning.
CHAPTER 1.

LITERATURE REVIEW

1.1 EARLY THEORIES OF LEARNING ASSOCIATED WITH PROBLEM-SOLVING

Many current ideas of modern cognitive Psychology can be traced right back to the earliest days of Psychology. Some account of this historical perspective shows the influence of early work on work of today.

It was the work of Charles Darwin in the nineteenth century which gave man a place in the animal kingdom, in 'The Origin of the Species' (1859). In his second major work, 'The Descent of Man' (1871) Darwin wrote: 'There is no fundamental difference between man and the higher animals in their mental faculties.' He maintained this belief throughout his life, that both physical and mental characteristics were fundamentally similar, although he did qualify it somewhat by acknowledging the wide difference in level between the mind of the lowest man and that of the highest animal.

During the late nineteenth century, this idea, that due to the continuity of all animal species, all behavioural patterns, including learning, were broadly similar, resulted in the introduction of animal experimentation into psychological laboratories, in the hope that their findings could be extrapolated to man.

The most famous of all these early experiments was the conditioning of dogs by the Russian physiologist Pavlov. By repeatedly ringing a bell simultaneously with feeding his dogs, Pavlov observed that one day the dogs salivated at the sound of the bell, in the absence of food — the dog was now conditioned to give a response to a new stimulus. So the relationship between a stimulus S and a response R — S-R theory — was born.

In America Thorndike (1911) developed this early idea of the stimulus-response bond, or connection, as the basic unit of behaviour. The chief way these S-R connections were formed, Thorndike believed, was through random trial and error, and he is credited with coining
this phrase. In his 'law of effect' he stated that responses to a situation which are followed by a rewarding state of affairs will be strengthened, or 'stamped in' as habitual responses to that situation, thus strengthening the S-R bond. Watson (1916) also built on Pavlov's idea of the conditioned reflex, emphasizing the need for such a scientific approach in psychological research.

So the early behaviourists defined a living organism in completely mechanical terms, and saw behaviour as 'atomistic', in the sense that it focused on the elements of the situation. Attempts were made to identify all stimuli and to describe behaviour as the product of numerous discrete reactions; thought, insight or purpose were not involved.

Further details of this early work may be found in most major books on the theories of learning, e.g. Hilgard and Bower (1975).

Early this century a group of German psychologists developed an opposing view of animal and human learning. Led by Wertheimer, they rejected the idea that a 'whole' can be understood by studying its constituent parts, and used the German word 'Gestalt' for which the closest English translation is 'a configuration', or 'an organized whole', in contrast to a collection of parts. They developed this idea first in relation to perception, and demonstrated that an individual spontaneously imposed order on a perceptual field, forming groups or patterns relating to the field as a whole. Consequently this has become known as the Gestalt field theory.

Kohler (1929) one of Wertheimer's followers, gave a simple illustration:-
Although there were six random dots, they were seen as members of a larger whole, i.e. two groups of three, without previous knowledge or experience. Subsidiary factors, such as similarity, proximity, symmetry with the surrounding field were further identified through animal experimentation.

Gestalt psychology had its start and achieved its greatest success in the field of perception. Interest in learning came later and the general laws of the organization of perception were applied to learning. Gestalt psychologists described learning as the development of 'insight', defining insight as a sense of, or feeling for, pattern or relationship. Insights were 'sensed', often as vague 'hunches', rarely verbalized, and always personal. They were interpretations of one's perceived environment, and formed the basis for designing subsequent action. In viewing learning as purposive, explorative, imaginative and creative, they broke away completely from the mechanical idea of links or associations of reflexes, developed through chance. Gestaltists criticised the behaviourists in their experimental design, stating that experiments were so arranged that the development of insight would not show, even if it occurred. In an attempt to refute mechanical learning, the Gestaltists designed problem-solving experiments which animals could only resolve through insight.

Kohler (1925) described several experiments with chimps. His most famous one was the out-of-reach banana, where the chimp pushed over a box, climbed up, and reached the banana. Kohler interpreted this as intelligent problem-solving — that the animal could survey the relevant conditions and 'think through' a strategy. Repetition of the successful act, and imitation by others was called insight learning. These experiments were among the first observations of complex problem-solving.

Bertrand Russell (1927) agreed that different types of responses in animal experiments could be attributed to the experimental design, and observed humorously that American animals learned by an energetic process
of trial and error, while German animals sat down and waited for a flash of insight.

Wertheimer's book (1945) was written late in his life and published posthumously. Both he and Katona (1940) used mathematical problems, and discriminated between rote-memorizing — the learning of senseless material by repetitive drill, and productive thinking — comprehending the meaning or underlying principle, and identifying the organizing factors. He contrasted a 'blind' solution to a problem as one where the learner applied a formula, often unsuccessfully, (implicitly criticizing the behaviourists) with a 'sensible' solution, where the learner understood the essential structure of the situation. This was demonstrated by being able to find the area of figure A, but not figure B, by understanding the area of a rectangle:

A  
\[ \text{rectangle} \]

B  
\[ \text{rectangle} \]

Two other Gestalists who studied individuals solving complex problems were Koffka (1929) and Maier (1930). In his string-tying problem Maier reported that the solutions came as 'wholes' in 75% of cases, i.e. the self-reports did not show any steps in thinking immediately preceding the insightful solution. In his problems Maier used a control and an experimental group. The control received no specific instruction, the experimental group had a prior lecture on the direction of thinking and new ways of structuring the problem. He reported better results in the experimental group.

Duncker (1945) was also interested in the initial 'ground' or cause of a problem, its 'set' or direction and the need to restructure problems in order to solve them. He analysed in detail partial solutions
and unsuccessful attempts, grouping them into hierarchies or 'family
trees'. He discussed 'analytic and synthetic explicability' and also
distinguished between 'phenomenological knowledge' and 'inductive logic',
but his use of mathematical symbols and problems together with his
persistent use of untranslated words made some of his points very
obscure.

These main Gestalt-influenced psychologists, working primarily
between 1930-1945 studied human problem-solving using real-life problems
and familiar materials. They were concerned with the quality of the
solution rather than the speed or quantity of the output, and distinguished
between 'good' (sensible, insightful) and 'bad' (blind, routine) errors.
In their interpretations they emphasized the whole, rather than the
analytical, trial-and-error method of solution.

Gestalt psychology was eclipsed during the 1950's and 1960's, and
American psychological research was dominated by what became known as
the neo-behaviourist school. It is interesting to speculate why. The
idea of 'insight' was a rather mystical, all-or-none phenomenon which was
not easy to test scientifically, nor was introspection considered
acceptable 'scientific method'. Hilgard (1964) has described the
'fall of Gestalt' as a process of neglect, or even transformation, rather
than due to disproof. The re-awakening of interest in problem-solving
could, he forecast, herald a revival of some of the earlier Gestalt ideas.
Today, many workers refer to Wertheimer (1945) without mentioning the
term 'Gestalt', or 'insight'.

Studies of animal behaviour continued to be dominated by the
neo-behaviourist school. Growing out of the earlier S-R classical
conditioning, from 1930's up to today, Skinner analysed more complex
forms of behaviour, in the belief that ultimately all behaviour will be
understood in terms of the basic S-R unit.
Skinner (1938) applied strict scientific method of hypothesis-testing, and in his experimentation he rigorously identified and controlled his variables, using his famous 'Skinner box'. He moved from classical conditioning, where the response was elicited by a known stimulus to 'operant conditioning', where a random response (an operant) was increased by a reinforcing stimulus — i.e., reinforcement was contingent on the response occurring. Learning, according to the neo-behaviourists, involved new reaction patterns arising from the interplay between a passive organism and its environment. The key concepts were still the stimulus (from the environment), and the response (the reaction given by the organism), and complex behaviour patterns were seen as chains or associations of S-R relationships. In criticizing current teaching practice as being completely against the principle of reinforcement, Skinner (1954) developed the idea of programmed learning, where a program of instruction was broken into steps, with immediate reinforcement and feedback at each step. A more detailed account of Skinner's work is beyond the scope of this thesis.

Studies into human learning have now differentiated into several fields — perception, reasoning and information-processing. There is general agreement that learning is a complex, integrated activity with a multiplicity of variables. Most models are inadequate in dealing with complex systems of organization, and Skinner's theory has been currently recognized as inadequate to totally account for all human learning.

These two theories of human learning, S-R associations and Gestalt, foreshadowed much of modern cognitive psychology. These theories were quite separate from another area of psychology which was concerned with the nature of intelligence, and which a brief history enables greater appreciation of current studies into learning and problem-solving.
Early studies of the structure of human abilities employed the use of factor analysis — the mathematical technique for identifying the relationship between variables in a complex pattern of overlapping influences. Statistical methods, however, do not define variables, they merely give numerical differences which are then given subjective names. Nor can any method of analysis, no matter how sophisticated, analyse what is not there, it is totally dependent on the original material. The numerical results by factor analysis do not give an objective description of the variables which may be applied to other data. So it is a tool, and not an end-result of experimental analysis.

Spearman's (1946) development and use of factor-analysis of test batteries led him to postulate a two-factor theory of intelligence. One was a general intelligence factor, the second a factor entirely specific to the particular task. Later in his life Spearman and Wynn Jones (1950) acknowledged this theory to be incomplete.

As reviewed by Vernon (1950), most British psychologists adopted a hierarchical structure of major, minor and specific group factors involved in human intellectual abilities. In contrast, American workers believed in multiple abilities of more-or-less equal status and influence. Thurstone (1938) identified a simple structure of seven primary mental abilities: spatial, perceptual speed, numerical, verbal learning, memory, verbal fluency, and inductive reasoning.

The most detailed studies in this field have been directed by Guilford, who I have classed in the next section on recent cognitive theories.

1.2 RECENT THEORIES OF LEARNING AND THE STRUCTURING OF KNOWLEDGE

Guilford's central interest was to design a more comprehensive model of human intellectual abilities. Using factor analysis, he developed his structure-of-intellect (SI) model (1956). Guilford
conceived a three-dimensional cubic model, containing no less than 120 abilities. He identified:

(a) 4 content categories (figural, symbolic, semantic, behavioural),
(b) 5 operation categories (cognition, memory, convergent and divergent production, evaluation)
(c) 6 product categories (units, classes, relations, systems, transformations, configurations).

Of all these abilities, most attention has been focused on the operation categories. This group was sequential: 'cognition' was used as 'knowledge', the most basic level; memory followed; convergent and divergent production together were more precise terms to define 'reasoning'; and the highest operation was evaluation.

Of these 'operations', divergent and convergent production are the most widely known. Guilford (1967) defined divergent production 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 also involved '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'. Convergent production involved drawing 'logical conclusions', divergent production generated 'logical possibilities'. According to Guilford the six convergent production × product possibilities described in more detail the traditional concept of 'deduction'.

Hudson (1966) extended Guilford's convergent/divergent tests considerably and found among Arts students, boys aged 14-15 years old, a ratio of 3-4:1 were classed as divergers, whereas Science students were found to be 3-4:1 convergers.
Hudson was ambiguous about whether these two characteristics were alternative representations of the one skill or were separate skills. For instance he talked about 'convergers' and 'divergers' suggesting alternative, mutually exclusive types. Then he added another group, the 'all-rounders' (which appear to be students who did not show a consistent pattern of characteristics of either group). This could be either an inconsistent single skill, or two skills. He went on, however, to discuss a spectrum, and even quantified it:

\[
\begin{array}{ccc}
\text{divergers} & \text{all-rounders} & \text{convergers} \\
10\% \text{ extreme} & 20\% \text{ moderate} & 40\% \\
20\% \text{ moderate} & 20\% \text{ moderate} & 10\% \text{ extreme}
\end{array}
\]

It is difficult to know whether some of the criteria Hudson used in his classification were pre-determined and used in classifying students or a characteristic found after classification, for example:

Convergers 'omit people from their drawings', 'look at the special properties of a gadget, such as a computer', and 'discuss impersonal aspects of culture'.

Diversers are the opposite of all of these, and in addition 'have more conceptual freedom'.

There was a rather large jump from Hudson's actual data (which was very detailed but still from essentially simple problems) and his degree of interpretation, but this study is significant in its deliberate attempt to collect richer data in both written, artistic form, and by interview, in contrast to Guilford's complex statistical measures of trivial tests.

In the U.S.A., convergent production has been linked with intelligence and divergent production linked with creativity. Hudson (1966), found no correlation with tests for creativity in his studies. Guilford himself
stated that creative potential was more complex than his divergent production tests allowed. He found, however, a high correlation between his convergent production tests and high IQ test results. A large study of creativity has since been done by Getzels and Jackson (1962) and Getzels (1964) discussed the relationship between creative thinking and problem-solving. Further comments on the nature of creativity are beyond the scope of this thesis; this topic has been critically reviewed by Wallach and Kogan (1965), and Vernon (1970).

Guilford's systematic approach gave the appearance of a scientific classification, more than his testing procedures warranted, for although divergent production tests required the student to produce his own answer, the questions used for assessing creativity were of the type: 'How many ways can you use a brick?'. He mentioned 'insight' or inspiration when discussing creativity, and accepted that there was considerable anecdotal information on the 'sudden flash' of a solution, but did not fit it into his SI model. He also proposed a complex flow chart of problem-solving, which he attempted to relate to his model, but which did not distinguish between convergent and divergent production. Overall this S.I. model with its enormous number of abilities seems to have little practical application.

It is interesting to compare Guilford's operation categories with those of Bloom (1956). Together with a number of educators, Bloom designed a hierarchical set of categories to assist in measuring the level of learning, i.e. outcome or achievement. Bloom categorized intellectual skills and abilities into six 'educational goals':

1. Knowledge — 'the recall of specific facts, terminology, definitions, classifications, ways of organising knowledge, practical techniques, generalisations and theories.'

2. Comprehension — 'the lowest level of understanding.'
the ability to translate data from one form to another (verbal → mathematical), to interpret and extrapolate from data, to solve familiar problems (to calculate).

3. Application — 'the ability to apply knowledge, and skills, to a new situation. The methods and principles are not identified in the question.'

4. Analysis — 'the ability to analyse information into its various parts, to show the inter-relationship or pattern of organisation, distinguishing facts from hypotheses.'

5. Synthesis — 'putting together/combining of parts into a coherent whole, producing a flow, formulating hypotheses based on a data analysis.'

6. Evaluation — 'making judgments about the value of information and methods.'

Although it was not proposed nor tested as a basic theory of learning, it is remarkably similar to Guilford's operation categories.

The studies done by the Swiss Jean Piaget broke completely away from traditional psychometric studies of absolute knowledge and abilities, and began to focus on students' perception of knowledge. Using 'task interviews', Piaget gave individual students a series of concrete problems and asked them to reason aloud. The problems were about the physical properties of matter. From these patient and meticulous observations Piaget developed his theory of the stages of intellectual development, translated by several workers (e.g. Ginsburg and Opper 1969). The four stages identified, sensori-motor, pre-operational, concrete operational and formal operations were identified by Piaget as being primarily age-related; each stage being passed through in an unvarying sequence for different topics, i.e. the thinking of a child was qualitatively different from formal adult thinking. It has been this age — rather
than experience — relation which has been the most controversial part of Piaget's work.

A fundamental idea underlying Piaget's work was his concept of mental structures. These structures functioned to organize the environment so that the individual could interact successfully with it. Piaget believed that in the course of intellectual development from infancy to adulthood these mental structures were constructed and reconstructed within the brain — they represented our knowledge about the real world and the world of ideas. Mental structures were not 'photographs' of the world, but were developed as new knowledge was 'assimilated' or added into his existing set of theories, and in turn these new structures altered or 'accommodated' existing theories. In this way the development of structures occurred not from within the individual, nor from within the environment, but from the individual's dynamic interactions with the environment, — 'equilibration'. Experience therefore was an essential part of meaningful learning.

Piaget believed these two complementary operations of accommodation and assimilation remained unchanged throughout life. Finally when equilibrium was reached the two operations were in balance, as in adult 'intelligent' behaviour. This equilibrium was not achieved all at once, but developed by successive equilibrations of increasingly complex functions.

While most researchers in developmental psychology acknowledge the historical value of Piaget's work, his ideas have been increasingly criticised. Brown and Desforges (1977) cast doubt on the integrity of the hierarchy of stages in development, pointing out that Piaget's hypotheses have never been actually tested, in order to eliminate alternative explanations, and that replication studies were merely illustrative and not confirmatory of the meaning of his theory. Anthony (1977) criticized Piaget's insistence on the physical manipulation of objects in learning.
Piaget consistently analysed data into stages. In studying the child's conception of the world (1973), he identified four stages in the development of animism, (i) generalized activity, (ii) movement, (iii) spontaneous movement and (iv) restricted to plants and animals. Other 'notions' studied included consciousness and time (1946). In all these studies Piaget observed a successive decrease in ego-centricity, 'decentration'. Similarly, Laurendeau and Pinard (1962) identified five stages in the development of causality, using a combination of Piagetian type experimental observations and conventional intelligence testing procedures to cross-check validity.

In addition to its meticulous observation, and despite criticism of his interpretation of his observations, Piaget's work was exceptional for its accurate, detailed reporting of full methodology, enabling world-wide replication studies.

For most of his life Piaget studied children, and ignored the level of formal operations. This ability to reason hypothetically and independently of one's environment Piaget saw as a stable, permanent state. In his most recent paper, however, (1972), he turned to the period between adolescence and adulthood, and made several contradictory statements to his general theory.

After concrete operations, Piaget identified a transition stage from 11-12 to 14-15 years, where children begin to reason hypothetically and deduce the consequences of these hypotheses. Before this age, reasoning was only applied to particular objects in the immediate present, and beyond 15 years, Piaget believed, full adult logic was achieved, i.e. the listing of all particular hypotheses and the subsequent progressive testing to isolate variables. Piaget identified two new processes — combinatorial ability (the relationship between elements) and propositional logic (combining propositions), i.e. the adolescent's logic was a more complex system which was different from the child's, and which contained the essence of adult logic.
After conflicting reports about this age-range elsewhere in Europe, Piaget admitted that his sample had been from a 'privileged population', and offered three possible explanations for the observed differences:

1. differential speeds of development through the stages and the role of particular social environments in facilitating or retarding this,
2. aptitudes of individuals differentiated progressively with age. (This is rather similar to Spearman's (1946) general and specific intelligence factors),
3. individuals reached this stage in areas according to their aptitudes and their professional specialization. Piaget admitted 'in our studies of formal structures we used rather specific types of experimental situations, of physical and logico-mathematical nature, similar to those used for school children.' Piaget then contradicted himself by accepting that his experiments may be subject-specific, but still stated that formal operations were independent of actual content. He stubbornly maintained that cognitive structures were similar in all young children but postulated that these structures may not be adequate to account for the variety of areas of activity in the adolescent age-group.

Throughout his work Piaget has looked for similarities between individuals, and accounted for differences in terms of being at a different stage of a mono-developmental process.

Piaget's classical task interviews are a laborious method of observation, so attempts have been made to design written problems. Renner (1977) designed several such problems, some of biological content, and validated them against parallel task-interviews. (His dinosaur problem, discussed in Chapter 4, originated from these validation trials). He reported after extensive studies that only 25% of American high-school students, mean-age 16.75 years, were at the Piagetian stage of formal operations. Similarly, Haj-Issa (1978) found that in a population of 788, fifteen-year-old Physics Kuwaitan school students, only 18% had reached this stage.
The vast majority of Piagetian studies have concentrated on the 9-14 year old age group, studying concrete reasoning, which is beyond the scope of this thesis.

In recent years the direction of research into learning has steadily moved away from extrapolations of non-human learning, or by humans learning nonsense, or very simplified tasks, in order to study more complex human learning, with its consequent application to education.

Ausubel's interest in learning theories arose from its application to teaching and improving meaningful learning in the classroom. His definition of a 'concept' has been included in 1.3.

In 1968 he put forward a concept assimilation - structural hypothesis to explain how knowledge may be organized. The essence of his view was that as new ideas were linked to relevant existing ideas, the overall organization of ideas could be represented as a hierarchically ordered pyramid structure, with the broadest most inclusive ideas ('superordinate' concepts) at the apex, and differentiating progressively into relevant subordinate concepts, (subsumers), towards the base. In meaningful learning, according to this structure, new material interacts with existing anchoring ideas and the meanings and significant relationships derived from the assimilated material were available for use in future. Rote-learning in contrast, involved no significant interaction with existing structures, a 'replica' of the particular material being held in isolation for subsequent verbatim reproduction only, and with a lower retention span.

Between these two extremes were learners with various incomplete subsumers for a particular learning task, and misconceptions could arise if students did not have the prior experience for complete development of concepts.
Ausubel believed that the same hierarchical organization of knowledge, based on progressive differentiation, holds true for all ages, the difference in young children being the number of abstract concepts, and the need to depend on a support of concrete-empirical material to assimilate new concepts. In this he differed significantly from Piaget's belief in qualitative differences, discussed earlier.

Ausubel described conceptual development as a continuous series of reorganizations in which 'existing concepts are modified as they interact with new perceptions, ideas, affective states and value systems.' This correlates closely to Piaget's idea of accommodation. Further, he stated that the highest level of abstraction in concept acquisition was reached during the stage of abstract logical operations, (cf. Piagetian formal operations), where higher-order, secondary concepts were related directly to cognitive structure without any concrete-empirical supporting material. The existence of relevant background knowledge, through experience, was therefore crucial in Ausubel's model.

Ausubel defined problem-solving as the reorganization of prior experience and the components of a current problem situation in order to achieve a designated objective. He identified two principle kinds of problem-solving, which could occur at all ages:

a) trial-and-error approach, consisting of random or systematic variation of available alternatives, often shown in problems containing no meaningful pattern of relationships (e.g. mazes), (reminiscent of the early behaviourist school),

and

b) the insightful approach which was a deliberate attempt to formulate a principle or discover a meaningful means-end relationship underlying the solution of a problem, (reminiscent of Gestalt psychology).
Characteristically, insightful solutions appeared to emerge suddenly, or discontinuously, and transferability to new problems was one of the most important criteria of insight. The utilization of hypotheses was a necessary, but not a sufficient condition of insightful solutions.

Ausubel did not believe problem-solving was a generalized 'trait', but varied on the basis of interest, experience and aptitude in different fields.

He disagreed strongly with Guilford's view that creativity was a general ability comparable with divergent thinking, taking a much narrower view that it was not content-free but was rare, developed insight in a particular area — . 'there is no such thing as 'the creative individual' as we acknowledge the generally 'intelligent individual'.

Ausubel recommended independent novel and unfamiliar problem-solving as the only feasible way of testing whether students really comprehended meaningfully the ideas they were able to verbalize. Even then it was possible, according to Ausubel, that a student who was unable to solve a problem did not necessarily understand, because problem-solving 'demands other abilities such as cognitive style, flexibility, improvisation, and an ability to integrate ideas, in addition to comprehension of the underlying principles'. This seems somewhat in contradiction to his definition of meaningful learning, and is one of his few acknowledgements of the role of the students' perception in learning, in his otherwise knowledge-orientated theory.

Ausubel cited evidence from several other workers in support of his claim that meaningfully-learned material was retained more effectively, and was transferable, than rote-learned tasks. No evidence was presented as to whether meaningfully-learned material was retained longer than rote-learned.
From this hypothetical base, Ausubel developed his theory of conceptual learning. He coined the term 'advance organizer', an initial abstract statement to act as an anchoring idea to facilitate subsequent assimilation of new knowledge. Much of the evidence about the effectiveness of advance organizers was indirect and capable of alternative interpretations, as has been reviewed by West and Fensham (1974). They pointed out that 'the existence of relevant subsumers does not per se guarantee that they will be called into play to produce meaningful learning. There is the chance that the learner will embark on a process of assimilation using irrelevant prior concepts, and consequently develop misconceptions about the new material. West and Fensham concluded that Ausubel's theory could be extended into a theme-approach which might prove useful for science teachers in developing courses that facilitated meaningful learning, rather than merely unrelated 'topics'.

Novak (1977) was extremely enthusiastic about Ausubel's concept assimilation theory and its application to education. He was critical of both the quality of educational research (in both methodology and theoretical foundation) and the proportion of Piagetian type studies (estimated at 20% of 400 recent research reports). He believed there was no fundamental conflict between Ausubelian and Piagetian ideas but that Ausubelian interpretations should supplant Piagetian views of cognitive differentiation.

Gagne's theories of learning, (1965, 1970, 1977), are the most difficult of all to follow, as they develop in seemingly discontinuous steps.

His early work was based on the simple S-R learning theory, describing a hierarchy of S-R associations from signal-learning, stimulus-response learning, chaining and verbal association.
This was extended to simple verbal learning → concept learning → principle learning → problem-solving.

As did Bloom and Ausubel, Gagne focused on the knowledge itself, and proposed a theory of learning based on structuring prior knowledge. Gagne later identified five capabilities, or domains of learning, all of which were orientated to the outcome of learning: (1) motor skills, (2) verbal information, (3) intellectual skills, (4) cognitive strategies, (5) attitudes, and described the conditions governing their learning. Two of these 'domains' were of particular interest:

(3) Intellectual skills — 'are the learning of basic rules and the use of definitions. Derived from external environment.' These corresponded to Guilford and Bloom's 'Comprehension' categories.

(4) Cognitive strategies — 'are internally organized skills that govern an individual's behaviour in learning, remembering and thinking'. 'They are derived from within' and 'are refined continuously with experience' (and by implication, age). These appeared to correspond to Ausubel and Piaget's idea of assimilation.

In his latest edition (1977) Gagne's detailed account of cognitive strategies included: ..... 'the internally-directed skills which learners use to regulate processes of (1) attending and perceiving, (2) coding for long-term storage, (3) retrieval and (4) problem-solving; i.e. how to learn, how to remember, how to carry out the reflective and analytic thought that leads to more learning, ..... and for which we may exercise a control as to which cognitive strategy to use...'

Throughout this he did not produce any direct evidence, and, in fact contributed very little to our understanding of what specific cognitive strategies may look like in operation.
In 1978 Gagne and White revised the 'domains and capabilities' idea in terms of memory structures. They postulated four components of interrelated memory structure:

**MEMORY STRUCTURE**

- **PROPOSITIONS**
- **IMAGES**
- **EPISODES**
- **INTELLECTUAL SKILLS**

**OUTCOME**

- **KNOWLEDGE STATING**
- **drawing**
- **identifying action sequences**
- **RULE APPLICATION**

Intellectual skills were still present, but cognitive strategies and other processing skills were omitted, without explanation. It is difficult therefore to reconcile this model to his earlier domains of learning. The 'instruction + memory structure' component was discussed in the application of this model to teaching, but attention was focused on structuring the medium of presentation according to the particular material and the most suitable memory structure, as though there were an absolute, best way of memory processing for a particular piece of knowledge.

At best this latest idea was an attempt to embrace both the structure of the knowledge itself (his primary concern) and the individuality of the student, but he did not go into any detail of individual differences represented within his idea of memory structures.

Bower (1970) and others, using free recall of verbal learning, have studied organizational factors in memory. Anderson and Bower (1973) have reviewed other studies of the subdivision of memory into discrete chunks. Further discussion of memory is beyond the scope of this thesis.

Novak (1977) compared Gagne's and Ausubel's models of progressive concept development. Whereas Gagne believed first in mastery of the
smallest conceptual units up to the general and more inclusive (i.e. an empirical approach), Ausubel recommended direction from the more general to specific subordinate concepts in the process of differentiation of cognitive structure.

Diagrammatically:

```
key:
Gagne: ---------
Ausubel: ------

Most general, inclusive concepts (superordinate)

Intermediary concepts

Most specific concepts (subordinate)
```

Both Ausubel and Gagne have described a logical organization of knowledge as an increasing construction of pyramids-within-pyramids. As compared by Novak they would appear completely opposite in their views of the 'correct' sequence of learning. Both workers have theorized about the use and extension of attained concepts; however little empirical research has been reported.

All of these recent workers in learning theories concentrated on the factors individuals had in common with each other, in order to develop a general hypothesis which would include all observations. Most workers have used factor analytic methods and many used multiple-choice questionnaires in their methods of 'observation'.

It should be emphasized that the major focus of these workers, (Bloom, Guilford, Ausubel and Gagne) was in terms of outcome, or quantity, of the knowledge itself, (i.e. an absolute frame of reference) — and this is what they used as their criteria of measurement. Built into these hierarchies is a value judgement — the aim of the teacher is to help students reach the upper levels of meaningful learning, and conceptual attainment.
Ausubel's theory focused on conceptual understanding. Further studies into the nature and learning of scientific concepts are described in the following section.

1.3 RESEARCH INTO CONCEPT UNDERSTANDING

There has been little agreement over the precise definition of the word 'concept'. Its popularity in education research has grown and its use has become virtually synonymous with the word 'definition'. In outlining their earliest stages of 'concept' formation, Klausmeier et al. (1977), for example, discussed the 'concept' of 'pens' and 'dogs'. A classificatory component in the meaning of the word 'concept' has been generally accepted, e.g. Bruner (1956) described concepts as 'categories'.

In attempting to distinguish between levels of concepts, several workers, (Gagne 1970, Klausmeier et al 1974, and Herron et al 1977) have analysed concepts into:

1) Concrete concepts, i.e. groups of perceptible instances or objects, with clear attributes (e.g. pens). Herron et al further identified:

2) Concepts with no perceptible instances. Included in this category were the names of objects with no perceptible attributes, (e.g. the name of a chemical compound) and the names of processes (such as oxidation). Since there were no examples with perceptible attributes, there were no useful non-examples to test for the learning of such a concept. Herron concluded that these concepts can only be learned at a formal level. It was in this second group that most scientific concepts belonged.

Ausubel (1968) defined a concept as 'the simplified and generalized representation of reality, rather than a complete and faithful sensory representation of it .... therefore concepts are essentially abstractions and do not exist in the real world, and are bound up with the development of language'. He arranged concepts into a hierarchical order, with higher-order concepts being progressively more general and inclusive —
a pyramids-within-pyramids structure; as already described in 1.2, and recommended teaching from the highest-order, most-inclusive concept to the lowest-order, most particular concepts. In developing formal concept understanding according to Bruner, a student's reliance on the use of examples is replaced by reliance on language.

Despite these differences, all these workers have agreed that when formal understanding (or attainment) of a particular concept has been achieved, the individual can define its critical attributes, and consequently accurately recognize new or unfamiliar instances of it.

There have been few systematic studies of biological concepts and almost none with higher education students. The majority of biological researchers have been strongly Piagetian-influenced.

Ausbefel's theory of cognitive structure has been applied to several studies of biological concept attainment.

Kuhn and Novak (1971) have studied the effect of using Ausubelian advance organizers for two biological concepts; 'the levels of biological organization' and 'homeostasis'; using female students in their first year of a University biology course. Using multiple-choice tests, (described as at 'information recall on knowledge level') in pre-tests and a series of post-tests from 0-6 weeks later, they found that the acquisition and retention of meaningful material 'appeared to be enhanced' (i.e. rather low statistical significance), by the introduction of relevant subsuming concepts (organizers) prior to, or coupled with, the learning experience.

Their fundamental assumption was that individuals assimilated new material into their memory structure in the same way. They focused on the structure of the material and the hypothetical structure of memory, and measured the outcome of amount of knowledge learnt, i.e. a 'how much' rather than a 'how' approach which considers individual differences in the learning process.
Lawson (1975) believed that mental structures leading to abstract formal thought could be developed in students if teachers structured new material appropriately. He recommended that a sequence should begin with 'the presentation of an undifferentiated whole' and used the example of introducing the formal concept, 'evolution' with the idea of gradual change over time'. This corresponded almost exactly to Ausubel's idea of an 'advance-organizer'. He then recommended a problem-solving approach, 'how do these changes occur?' to 'differentiate the whole into its related concepts'.

Lawson, Nordlund and de Vito (1974) using five of Piaget's classical tasks with American college students (mean age 18.5 years) found that most students were in the concrete-operational stage on all tasks. They questioned the age-related development as the primary determinant and suggested an alternative explanation in Ausubelian terms of the absence of specifically relevant differentiated concepts.

Most recent biological studies in the U.K. have stemmed from the introduction of Nuffield Biology in the late 1960's. This course presented senior secondary Biology on a discovery-learning model, with major emphasis on practical experimentation to demonstrate basic concepts.

Head (1975), using a written questionnaire, evaluated the long-term effects of Nuffield Biology on student performance by contacting both post-Nuffield tertiary students and their tutors. Students stressed that they were deficient in the 'factual knowledge' assumed in their courses of various biological studies.

Shayer (1974) used Piagetian criteria in his analysis of the Nuffield O-level course. After estimating that formal thinking for able children was 13.5 - 14.5 years, and 15.5 years for average children, he advised that several parts of the course were beyond the conceptual capabilities of the designated students, and recommended the evolution/heredity section be omitted entirely.
Deadman (1976) investigated the understanding of the concept of evolution in 11-14 year old boys, using focused interviews. Before formal instruction in this concept, he found poor understanding of the principles of Darwinian evolution due to poor subordinate concept formation. Deadman and Kelly (1978) developed a teaching scheme based on Ausubel's theory to overcome children's intuitive ideas of 'change on the basis of need' (Lamarckian evolution) and other naturalistic ideas. Neuberger (1966) described similar explanations of 'change' by American 10-11 year old children.

Bainbridge (1977) recommended the use of concept maps in teaching microbial genetics, to help tertiary students integrate their knowledge rather than learn 'pockets of unrelated information'. He criticized the use of modular systems in fragmenting subject matter, leaving the student to integrate and synthesize his own ideas.

Shaefer (1979) defined a 'concept' as consisting of a 'logic core', which was the invariant properties of a class of things, together with an 'associative framework' — a surrounding network of associations which coloured the concept with sensory attributes, emotions and with other concepts, linked often by coincidence in time. (This seems similar to Pask's redundant holism, see 1.4).

By means of word associations and free definitions, Shaefer studied the concept of growth in German upper secondary students, High school biology teachers, and University biology teachers. He categorized the association chains into physical, biological and sociological interpretations. He reported a marked change from growth seen in terms of a geometric dimension to growth in terms of numbers of particles with increasing age, but did not draw any conclusions as to the significance of this.

Research on the learning styles of the 18-22 year old tertiary students is steadily increasing. Both problem-solving and interview methods have been used to explore students' perceptions of, and cognitive styles used for several basic scientific concepts.
Shavelson (1972), using a text passage of Newtonian mechanics and cluster analysis methods of word associations found that cognitive structure corresponded more closely to content structure than in a parallel control group. This seemed to be overinterpretation of simple data.

Cowan (1977), using engineering problems, asked University students to 'think aloud' as they worked through complex engineering problems. He found their recordings very difficult to analyse and described only an 'intuitive' difference between students' methods of tackling problems.

Osborne and Gilbert (1979) studied the way students of different ages (7-18 years) understood the concept 'work', using pictorial illustrations as instances, and found a sequential development from 'work is something you do' to the physics algorithm \( w = f \times d \), rather similar to Piaget's stages of animism and progressive decenteration.

Dahlgren (1978) gave University economics students a set of ten 'trivial' real-life economics problems involving the application of basic economics principles, in an interview situation. In prior course examinations these students had correctly solved considerably more complex problems, using algorithms. However he found many students were unable to identify the underlying concepts in novel, unfamiliar problems. Two groups of errors were identified, one group apparently being unable to consider a number of functions and parts of a system of interacting components, their attention was focused on single parts only'. Other students showed an increasing ability to consider larger and larger parts of an interactive system'.

Dahlgren pointed out that this difficulty in understanding the network of basic concepts or principles, together with the quantity of material covered in courses, may contribute to a rote-learning or surface approach to learning (described in more detail in 1.4).
One possible criticism of Dahlgren's set of problems is in his order of problems, for the first question was a direct definition of the concept contained in subsequent problems. By doing this he may have 'cued' some students (cf. Miller and Parlett 1974) and in reality his observations may have been even worse than reported.

In the last few years, attention on cognitive skills and abilities has largely switched away from the similarities to focus more on the differences between individuals. This led to the need to develop more sensitive techniques than the impersonal psychometric methods. As personal contact methods increased, it became impossible to maintain study populations at the same level, and so statistical analysis lost further suitability. 'Problem-solving' developed from relatively simple solutions to include complex problems, but the conditions, degree of control and the kinds of complexity and experimental design, all of which were termed 'problems', varied widely.

Evidence began to accumulate that students did not perceive or tackle problems in the same way, and some major findings in this area of research on learning are contained in the next section.

1.4 INDIVIDUAL DIFFERENCES IN STUDENT LEARNING

Interest in the outcome of learning, either the quantity (Bloom) or of the structure of knowledge attained (Ausubel, Gagne) has been paralleled with interest in the actual processes, used by individuals to produce this outcome.

One of the differences in approach most extensively studied has been the differences in field-dependence, first identified by Witkin. Witkin, Moore, Goodenough and Cox (1977), in their comprehensive review of this field described both the development of their ideas and also educational/vocational implications. Their interest grew out of differences in spatial relations ability and into embedded-field tasks
reflecting much of the early Gestalt school. They defined a bipolar continuum from field-independent, where a subject perceives part of a field as discrete from its surrounding field; to field-dependent where the organization of the prevailing field determined the perception of its components. They cited evidence that these were stable in individuals, also that women were generally more field-dependent than men. Moreover field-independent people were more likely to impose structures on material spontaneously, whereas field-dependent people usually left material 'as is'.

They then linked perceptual and intellectual abilities together to form 'cognitive style' — a characteristic approach to situations, and coined the dichotomy articulated-global style. However they still spoke of the field-dependence component, and linked various social, personality and vocational aspects to the two types, suggesting an extremely clear-cut distinction. Amongst their 'cluster of characteristics', they stated that field dependent individuals related to people better, while field-independent were more impersonal. They distinguished a 'spectator' vs. a 'hypothesis-testing approach to concept attainment tasks. In reviewing concept attainment they suggested that 'cues' which were useful for one concept definition may become irrelevant in the context of a new learning problem. They postulated that field-dependent individuals 'may have difficulty with the class of problems where the solution depended on taking some critical element out of its presented context and restructuring the problem material so that the item was now used in a different context'. This appeared to be a description of Ausubel's 'meaningful learning' and the transferability of concepts. They extended this to consider teacher adaptability, heterogeneous discussion groups, moderating variables and educational/vocational choices in field-dependence terms. They summarized the essential characteristics of cognitive style as: (1) deals with form (i.e. process) rather than content, (2) has broad dimensions extending into personality attributes, (3) is very stable over time (but not unchangeable) and (4) it is bipolar, but without a value component, (it may be specifically suited to the requirements of particular tasks or jobs).
Nebelkopf and Dreyers (1973), extending the work on field-dependence to very young children, (5 years), and using statistical analysis, found that pre-categorized field-independent children showed basically a linear, discontinuous progression through sets of tasks, (two-choice simultaneous discrimination cards), whereas field-dependent learning curve was non-linear but continuous. Again neither strategy was said to be more efficient, and these results again implied some consistency and stability. These observations were particularly interesting as they clearly suggested these differences in style were present at a very early age, in contrast to Piaget's theory of sequential intellectual development.

Bruner, Goodenow and Austin (1956), using modified Games theory methods, studied strategies of thinking and concept attainment. 'Concept' was defined as 'a grouping of things' into a single category. In their experiments students did not have to invent new categories, but used predetermined ones, and Bruner systematically studied the students' strategy of search and hypothesis elimination, using an array of cards with multiple attributes (shape, number, colour etc.) They identified two main strategies, scanning and focusing, and further subdivided these into simultaneous or successive scanning, and conservative focusing or focus-gambling, on the basis of the student's choice of cards to identify the correct characteristics of the 'concept'. The main difference between scanning and focusing was that the former successively eliminated hypotheses, the latter, attributes. In further experiments Bruner re-designed the material and distinguished between selection strategies, where the subject saw the whole array and selected instances freely, and reception strategies where the investigator selected instances and stated whether the instance was positive or negative. Bruner distinguished two kinds of concepts, conjunctive (multiple attributes), and disjunctive (mutually exclusive attributes), and found his strategies applied better
to conjunctive concepts, students finding it very difficult to handle the negative instances of the disjunctive concepts.

Attempts to replicate Bruner's work have found difficulty in distinguishing between simultaneous scanning and conservative focusing from the sequences of choices. Both Eiferman (1965) and Laurillard (1978) used student's introspective accounts to resolve this, but even after they outlined Bruner's criteria to students, the students themselves could not identify their own strategy. Bruner's neat results have been criticized as being subjectively biased.

Bruner (1960) extended his ideas into a model of thinking, identifying two basic kinds, analytic and intuitive. He characterized these as follows:

**Analytic (A)** — student proceeds step-by-step, steps reasonably explicit, student often uses maths equations or logic, with explicit plan of attack.

**Intuitive (I)** — student possesses an implicit 'feel' for the subject matter, and often arrives at an answer with little or no conscious awareness of the steps taken, and cannot explain how an answer was obtained.

These two categories were seen as separate classes, i.e. two abilities, and Bruner (1960) discussed their implications to education.

Thorsland and Novak (1974) extended Bruner's intuitive/analytic dichotomy, to study problem-solving approaches by students. Using tape-recorded interviews, with students 'thinking aloud', they observed tertiary physics students solve four physics problems. They found some students appeared to be able to switch approaches for different problems, whilst others used the same approach for different problem-solving situations.

Using Ausubel's model of conceptual organization, Thorsland and Novak represented the essential difference between highly analytic and highly intuitive students in terms of either movement primarily within
the sub-ordinate concepts (analytic), or between super-ordinate concepts (intuitive). As can be seen from their diagrams below, a possible criticism is the way they drew sub-ordinate concepts on the one level.

![Diagram of Analytic Concept]

![Diagram of Intuitive Concept]

It should be noted that these models and their I/A characteristics were pre-determined, rather than formulated after experimental observations. They formulated several hypotheses about the relationship of intuitive/analytic approaches to scholastic performance and learning efficiency and attempted to correlate their observations with these hypotheses. By using an ordinal scale, based on a ranking of 5 for each problem, and taking each ability separately, they obtained a student rating of a figure between 0-20 for both intuitive and analytic skills. On a two-dimensional I-A grid, a random pattern was obtained, but various statistical correlations were applied to these rather imprecise figures in an attempt to verify their hypotheses. Thorsland and Novak went on to study the learning efficiency of these students and found that although highly analytic students spent more time in the independent learning centre, the highly intuitive + highly analytic students were the most efficient at learning. They suggested that these two abilities correlated with intelligence and creativity, (similar to Guilford's convergent/divergent production), and pointed out that most schools consider only analytic ability.
They concluded that it was possible to identify, by interviews, consistent and reliable individual differences in problem-solving approach in terms of an analytic-intuitive dimension. A large variability existed in the population in these dimensions but individuals tended to be reasonably stable over time, particularly in the analytic dimension. Their further conclusions appear to be beyond the dimensions of their experimental design and indices of measurement.

Several studies have been made using reading-comprehension observations. Rothkopf and Bisbicos (1967) observed high school grades 10-12 students' approach to reading thirty-six pages of serial, independent factual segments. When simple factual questions were interspersed during the task they found that these students, but not the control group, retained the factual content when tested subsequently, suggesting that the questions had selectively directed the students' approach to the test. Similarly Watts and Anderson (1971) reported that the type of processing used by students was altered by questioning. Neither group named the types of processing identified.

Ference Marton's team in Sweden have focused on university students' perceptions of learning, i.e. how students conceptualize specific phenomena and apply them in practice. In an economics reading task, Marton (1975) identified two different approaches used by (paid) economics students. He distinguished a surface/deep dichotomy, using the following characteristics.

**Surface-processors** 'concentrated on surface aspects of the situation, on the discourse itself as an isolated event, and on subsequent achievement requirements. This attitude seemed to be associated with a passive approach, (i.e. 'learning is something that happens to you'.)'

**Deep-processors** 'concentrated on what the discourse was about, actively connecting what they were reading with what had
gone on before, and utilized their own capacity for logical thinking. They generally related their knowledge to everyday reality.' (Active learning is 'something that you do'.)

Nowhere in his reports did Marton record the precise instructions he gave to students. In the light of Rothkopf et al. and Watts et al.'s evidence above, this could be crucial in determining the kind of approach used by students. This incomplete data reporting made it difficult to replicate Marton's work, as Laurillard (1978) described.

Marton and Saljo (1976a) analysed students responses into hierarchical stages which they called 'levels of outcome'. This is a rather ambiguous phrase, since they were using it to describe 'what' and not 'how much'. Their stages were very similar to the stages of conceptualization of animism and thought, analysed by Piaget from their observations, Marton and Saljo (1976a) correlated outcome (i.e. how student performed) with processing (how students said they approached task).

In a subsequent study of reading comprehension using introspective methods similar to the early Gestalt workers, Marton and Saljo (1976b) showed that students could adapt their way of processing to the requirements of the task, but that such artificial manipulation may affect retention if it was mismatched to the student's method of processing.

Dahlgren and Marton (1976) correlated the 'deep' approach to general descriptions of students' study habits, obtained by open interviews, and further correlated the deep approach to better examination results. Few details about 'surface' learners were reported except that they read less and have poor exam. results.

Marton in general described an all-or-none categorization, suggesting a mutually exclusive, stable style of learning, i.e. one skill.

In subsequent papers, Marton (1978) emphasized the need to base research on the students' perspective of learning (i.e. to describe the world as people experienced it), a 'second-order perspective', rather than
on the achievement or outcome of the quantity of knowledge, the criteria of most educational studies. In this he echoed Piaget's central belief.

Overall, Marton's surface --- deep dichotomy does not represent much progress on the rote - memorizing—productive thinking described long ago by Wertheimer (1945). They seem to have ignored a considerable number of observed students who did not fit into either category. Marton saw these two levels of processing as 'implying a dimension along which students can vary', rather than two distinct and separate categories. However in correlating this dichotomy to students' study habits and subsequent exam. results he implied a very stable approach for an individual, at least in a particular subject. It is difficult to know the frequency of these types of approaches, from his figures, in the economics student population as a whole — has he observed the weakest students by chance, in his 'surface-processors'?

In such a clear-cut surface/deep dichotomy Marton seemed to have blended several criteria — most of all he confused 'level' (which implies 'outcome') with 'style' (how the student perceives the problem). This is discussed in more detail after outlining the work of Gordon Pask, and further in 8.1.

One of the most active workers in this area (and recently comprehensively reviewed by Entwistle 1978), has been Gordon Pask. His work on student learning has resulted in the formulation of two dichotomies. In 1972, using a learning task of the taxonomy hypothetical Martian fauna, Pask and Scott identified two distinctive learning strategies, serial and holistic. They then categorised students as being 'serialists' or 'holists'. In a detailed paper they made several comments to describe these types:

**Serialists**

'learn, remember and recapitulate a body of information in terms of string-like cognitive structures where items are related by simple data
links: formally by 'low-order relations'. Since they assimilate lengthy sequences of data they are intolerant of irrelevant information, unless they are equipped with an unusually large memory capacity'. Later, when describing how serialists 'teach-back' a learned task they described that serialists 'tended to preserve the order of presentation'. 'A problem serialists faced was failing to distinguish "the wood from the trees", and consequently amassing masses of sparsely related, if systematic, information'. In his summary of Pask's work Daniel (1975) introduced the phrase "step-by-step" learners.

**Holists**

'learn, remember and recapitulate as a whole: formally in terms of "high-order relations". They can be further sub-classified as redundant or irredundant holists. Both image an entire system of facts or principles. An irredundant holist's image highly interconnected and contains only relevant and essential constituents. Redundant holists entertain images that contain logically irrelevant or overspecific material, commonly derived from data used to 'enrich' the curriculum. These items are of great psychological importance to a redundant holist, since he uses them to access, retain and manipulate what he originally learned'.

In describing a 'teach-back' presentation, holists 'disrupted the order of presentation with virtual disrespect'. One problem holists experienced was the 'tendency to overgeneralise'. In his review of Pask, Daniel (1975) said holists gave a 'global' description of topics.

In support of this black and white division, Pask said students consistently preferred a particular type of learning strategy, although he did not present evidence to support this statement. In fact, of the sixteen students used, the one who did switch styles was omitted from the results. The significance of this was best demonstrated by Pask's next set of experiments. Having classified his subjects discretely into either serialist or holist, Pask prepared a second learning task (also a
taxonomy). Material for this second task was prepared in two ways — a serialist-learning programme and a holist-presentation. He divided his typed students into four groups: two groups were matched to their style (S - S, and H - H) and two were mismatched groups — where serialists were given the holist programme and holist students the serialist programme. The results of competence of learning were dramatic — both matched groups achieved virtually 100% mastery, while the mismatched groups learnt much less efficiently.

Pask pointed out the importance of this dichotomy of styles or strategies to educational practice: all educational material — textbook, course module, teaching programme is based on a teaching strategy which consequently directs the students' learning strategy. Moreover Pask believed there was a strong institutional bias to structure material towards serialists, and most examinations favoured serial recall.

In 1976 Pask added further descriptions of these classes:
'The serialist has one goal and working topic, which may be the aim topic ... and moves on to another topic only when he is completely certain about the one he is currently studying'.
In contrast, 'the holist has many goals and working topics under his aim topic .... and is assimilating information from any topics in order to learn the aim topic'.

Pask then made a major revision of his learning dichotomy, and stated that serialists and holists were extreme examples of 'a more fundamental process of degrees of learning'. Although he now claimed the distinction was in the level, and not in different classes, Pask still spoke of learners. His two types now became operation and comprehension learning:
Operation Learner — 'picks up rules, methods and details but is often unaware of how they fit together. He has at most a sparse mental picture of the material and his recall of the way he originally learned is guided
by arbitrary numbers or accidental features of the presentation. If provided with a specific description he assimilates procedures and builds concepts for isolated topics. His cognitive repertoire includes effective procedure — building operations.' 'C. learners had simple hypotheses.'

When he prepared a domain map for students to learn, Pask found that operation learners move vertically through the map. In a free-learning situation operation learners tended to act 'like serialists'.

Comprehension Learner — 'readily picks up an overall picture of the subject matter, and recognises where information can be obtained. These individuals are able to build descriptions of topics and to describe the relation between topics. Their cognitive repertoire includes effective, though individually distinctive description-building operations.'
'C. learners had complex hypotheses.'

In observing their learning of a domain map, Pask found that comprehension learners tended to move sideways across the map. In a free-learning situation comprehension learners tended to act 'like holists'.

Pask went on to say that for full understanding, a student must be versatile — i.e. able to use both operation and comprehension learning. This suggests that this dichotomy is not a characteristic of the student. In summary, Pask's two dichotomies may be represented:

```
<table>
<thead>
<tr>
<th>STYLE</th>
<th>DEGREE OF LEARNING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serialist</td>
<td>Operation ———— Comprehension</td>
</tr>
<tr>
<td>Holist</td>
<td>Versatile</td>
</tr>
</tbody>
</table>
```

What significant changes has this revision and new dichotomy achieved?

a) Pask has moved from a distinctive class of style, characteristic of a student, to levels, or degrees of learning. The important outcome of this is that he now identified the versatile student (able to do both) — in fact
'this is the desired goal of learning'. However he still stated that, 'left to himself a student reverts to a favoured style'.

b) In his definition of 'operation learner' (a more generalised form of serialist), Pask has lost the systematic step-by-step sequence of learning, for he now used the words 'isolated' steps, and 'sparse' mental image, which suggested a random approach to a learning task.

c) He made no attempt to further classify comprehension learners, but included additional quite different criteria in this group.

d) The original words 'serialist' and 'holist' were descriptive terms. 'Operation' and 'comprehension' were much less clear. Moreover 'comprehension' as Pask used it, was quite different from the 'level of comprehension' in Bloom's classification of intellectual skills, already outlined.

How different then were Pask's 'degrees of learning' and Marton's 'levels of processing'? If one identified key ideas in their definitions, then both operation-learning and surface-processing described a passive, memorising approach to isolated parts of a topic, with rote recall. Similarly both comprehension-learning and deep-processing were categorized by those students considering the topic as a whole, integrating various parts, and relating this topic to other experiences or knowledge.

One difference emerged — namely Pask extrapolated his dichotomy to a further level, where students achieved competence in both strategies. Marton's differences, surface-deep processing, could not be so extrapolated. Otherwise it seemed that both Pask's and Marton's dichotomies are essentially similar, in that both now were describing levels of learning.

In all of this, the fine definition of 'learning style', i.e. approach, has become completely blurred with 'levels of learning', i.e. outcome. This is further discussed in 8.1.

Pask's earlier work on 'styles' involved the serialist/holist dichotomy. One of the most significant findings in his work was the difference in efficiency of learning between students matched to their
style, and mismatched students who had to learn a task prepared in the opposing style. These earlier observations did not fit easily into his subsequent degrees of learning.

Both Pask's and Marton's findings suggested that their respective criteria were relatively stable in an individual. All these differences between individual students' approaches to learning have been documented in educational research studies in recent years.

Most workers have identified a simple dichotomy — i.e. two opposing and contrasting styles, into which all students have been divided. There has been Guilford's convergent/divergent thinking (1956), Witkin's field dependence/independence (1964), Bruner et al's scanning/focusing, Thorsland and Novak's intuitive/analytic approaches (1974), Marton's surface/deep level processing (1975), and Pask and Scott's serialist/holist (1972) and subsequent operation/comprehension learners (1976). Just how unique are each of these dichotomies? There are several reasons why so many categories have been described:

- All workers have concentrated on rather singular, but individually widely different methods and types of data collection. Subtle differences may well be artefacts due to these narrow sets of observations. For example Pask developed a series of very complex learning 'games', totally unrelated to any formal course of study. Serialists and holists were described from observing sixteen students learn two taxonomies of hypothetical fauna. Operation/comprehension learners were identified by factor analysis of data from two 24-hour intellectual games — either the 'Spy Ring Test', or the 'Smuggler's Test'. Bruner also has borrowed from games theory. Marton has worked much more closely to normal learning experiences, setting students a reading/comprehension task from either a set text-book or a selected passage. Thorsland and Novak set four physics problems.
On the basis of small numbers of students, and narrow data collection, all have generalised, developing theories of learning, and a multitude of 'dichotomies'. None of these workers seem to have identified which part of the learning process they were actually investigating. Dahlgren and Marton (1978) stated: 'All the dichotomies seem to relate more or less directly to two different conceptions of learning, namely learning as a transmission of unrelated "bits of knowledge" on the one hand, and learning as a change in one's conception of some aspect of reality on the other'. If this view is initially accepted as a starting point, (and this is criticised in detail in 8.1), and that these dichotomies are essentially all describing one intellectual skill, which for simplicity is termed 'cognitive or learning style' then one point of confusion still emerges. Interpretation of observations has been made on differing, implicit assumptions as to how many styles may be possessed by an individual. This point may be most clearly represented diagrammatically:

1. There is a single cognitive style, existing as a bipolar spectrum, on which individuals may be consistently placed (i.e. it is stable), i.e:

   e.g. Hudson: convergent—— all-rounder—— divergent
   Bruner: focusing—scanning
   Witkin: field-independent — field-dependent
   "articulated — global

2. There are different styles, but an individual only has one, independent of the task. (i.e. it is a mutually-exclusive characteristic of the student), i.e:
e.g. Wertheimer: rote productive
      Ausubel: rote meaningful
      Pask: serialist holist

3. There may be only one, or more than one style, the individual
can select the one appropriate to the task: i.e.

  --------------------------------------------------------
   
   e.g. Rothkopf and Bisbicos: unnamed
      Marton: surface deep
      ? Witkin: articulated global (Witkin is ambiguous: does student select
      appropriate job or does job dictate appropriate style)

4. There are two separate styles, and both can be present in
   individuals in different degrees: i.e.

   e.g. Guilford convergent : divergent
      Bruner analytic : intuitive
      Thorsland & Novak
      Pask operation : comprehension (rather vague, but because he says the
                           aim is to do both)

In understanding how students learn, it is vital to extend our understanding
of these differences in learning styles.

Concept learning and learning styles are thus both active fields
of educational research today. Their application to teaching is
increasing. It is in this framework that I now describe my investi-
gations, with tertiary biology students, into the learning of the
concept of Darwinian evolution by natural selection.
CHAPTER 2

RESEARCH DESIGN AND METHODOLOGY

2.1 FORMULATION OF THE RESEARCH QUESTIONS

The overall aim of this project was to explore the problems and variations experienced by students in learning the complex concept, Darwinian evolution.

The initial research questions were concerned with assessing the understanding of the key concept of natural selection:
Q1. What was the understanding, shown by students, of Darwinian evolution?
Q2. What were the major misconceptions?
Q3. How valid were different forms of written assessment (short open-response vs. multiple-choice) in assessing this understanding?
Q4. How had students who showed good understanding been taught this concept? How did they recommend teaching it?

2.2 METHODOLOGY STAGE 1. PILOT STUDIES

One of the criticisms of much research into human learning is that, in an attempt to specify variables rigorously, it has used nonsense tasks, or low-level problems in its data observations. Other workers have used mathematical problems for which it was possible to use a mechanical, or rote solution. Apart from the obvious limitations of such research, and the danger of only demonstrating 'S-R' type associations rather than any meaningful learning, the possibility of rather low student 'motivation' (i.e. interest and effort) in such tasks, especially at tertiary level, must be raised. Moreover, in their aim to quantify the 'general', these methods do not detect the details of the 'particular'.

In basing my methodology on a problem-solving approach, I used three novel or unfamiliar environmental instances of the concept of
natural selection, (i.e. they were not the standard textbook 'giraffe
and his long neck' examples.) Utmost care went into designing all the
problems in this project. The choice of content, the precise wording
and the layout on the page were given considerable thought. Some of
the problems may look simple, (perhaps similar to those that Dahlgren
and Marton (1978) have called 'trivial'). They certainly are not of
the complex and sometimes vague type frequently found at tertiary level.
Their clarity and conciseness were aimed to eliminate ambiguity or
misinterpretation, yet elicit thoughtful answers from students.

After these problems had been tackled, I asked a 'concepts
identification' question, to determine whether students had consciously
identified the underlying concepts.

The complete test, Stage 1, is contained in Appendix III. The
problems came from a pre-test, post-test set of problems, (in multiple-
choice format only), which I had designed for diagnostic use in Australia.
Distractors were based on incorrect phrases which had occurred repeatedly
in the previous year's state-wide exam essay on evolution. These three
problems had been incorrectly answered by all my students on the pre-test.

a) The written test.
The test comprised two sections. One section contained three questions
in an open-ended response format (OR), where the student was allowed a
half-page space to write his answer. A fourth question asked for concept
identification contained in these three questions. The other section
contained the identical questions, in a multiple-choice format (MCQ),
and the student was asked to circle the most correct answer. These two
sections were then stapled together in alternate orders, forming two sets:

Group 1. Order of sections OR/MC

The purpose of the order OR/MC was to obtain the students' basic
understanding of the question without any 'cues'. I was interested
in determining whether MCQs do put ideas into students' minds that
may direct their thinking.
Group 2. Order of sections MC/OR

The alternative group MC/OR was included initially to make this comparison. It is worth pointing out that this second group closely parallels a commonly used exam question structure of:
(a) MCQ, (b) give reasons for your choice/explain your reasoning (on lines provided).

A frontispiece for educational background details concealed the difference between the tests.

During early field work these two reciprocal types of tests were randomly distributed within the student groups participating. Students were not told of this difference in the order. They were only specifically asked not to alter any of their answers in the light of a later question, and this was carefully supervised.

Immediately following the test an informal open-ended discussion followed, where students were free to comment on any aspect of the test.

The validity of these pilot problems was further checked by full-test participation of eight post-graduate biological scientists (University lecturers, University of Surrey, and post-graduate Environmental Science teacher-trainees from University of Bath). Seven of these volunteers were categorized into 'sound understanding', using the method of analysis described in 2.8 and in 3.2, i.e. by correctly applying the concept of natural selection to all three problems, and correctly identifying the relevant MCQ alternatives. (The eighth volunteer had only studied Biology in the first year of a Science degree, and overall showed moderate understanding). In the concepts identification question, all eight listed several concepts, including 'natural selection', 'principles of Darwinian evolution', 'individual variation' and 'genetics'. Three also included 'adaptation' and 'immunity' as additional concepts.

A full description of the method of analysis, used throughout this project, is found in section 2.8 of this chapter, and the results of this
pilot written test form Chapter 3.

From this analysis I identified a group of students who had demonstrated sound understanding (defined in 2.9) of a selection process in evolution. Approximately six months after the test I contacted each of these students in order to discuss their teaching/learning experiences in depth.

b) Individual interviews:

I personally interviewed 7 out of the 9 students who comprised this 'sound' group. Each interview (which was tape recorded) lasted 30-45 minutes. Although these interviews were designed to be as open-ended as possible, I worded the key questions with utmost care. The remaining students had left University on vacation.

c) Written 'Interviews':

I carefully drafted a letter, containing my three key questions, to the two remaining students of the nine above. Both of their replies, 3 to 4 pages long, were informally written answers to my important questions, and were very useful. A possible difference between these two and the other seven was that these students read all three questions, before giving any answers. Their clear answers indicated this had not confused their thoughts.

Analysis of these interviews, as described in 2.8, served several purposes;

- to learn about students' experiences and suggestions of effective teaching methods,
- to give myself practice in interviewing before the main stage two,
- to give preliminary observations of differences in individual student's learning styles.

These observations are also contained in Chapter 3.
2.3 STUDENT POPULATIONS — STAGE 1

(a) British. A total of 63 first and second year tertiary students were given the pilot test during the first term. They were then enrolled in the following courses:

- Human Biology
- Microbiology
- Chem/Physics
- Science & Education
- Science & Education
- West London Institute of Higher Education

Of these students, 49 had studied Biology at A-level, within the last three years, 14 had no Biology background. Sex distribution and age-range are shown in the following table.

<table>
<thead>
<tr>
<th>Age-range</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 - 22</td>
<td>49</td>
</tr>
<tr>
<td>19 - 24</td>
<td>14</td>
</tr>
</tbody>
</table>

Results of these students are described in Chapter 3 of the pilot studies.

(b) American. Professor J. Renner, Professor of Science Education at the University of Oklahoma has designed several written problems to evaluate students' Piagetian levels of intellectual development. One of these problems, the 'Oklahoma Dinosaur Question' was given to 88 tenth, eleventh and twelfth graders (mean age 16.75 years) from 12 Oklahoma high schools. He kindly sent me their written explanations for analysis, which is described in Chap. 4.

2.4 FURTHER RESEARCH QUESTIONS — STAGE 2 AND 3: MAIN STUDY

During the pilot studies I had become acquainted with the work of David Ausubel, Gordon Pask and Ference Marton (1.3), and had extended my analysis of the pilot studies to include a preliminary study of learning styles (3.6). The differences between 'meaningful learning', 'learning
style', and 'processing', and the possible relationship to conceptual learning resulted in the formulation of further research questions.

Q5. How do students go about complex problem-solving, i.e. do they have distinct styles?

Q6. If they do show individual differences, then how consistent are these for different conceptual tasks?

Q7. What is the frequency of occurrence of such differences in a tertiary student population?

Q8. What is the relationship between learning styles, levels of integration and meaningful learning?

2.5 METHODOLOGY STAGE 2: STUDENTS PERCEPTION OF BASIC CONCEPTS

In the pilot study (Chap. 3) the MCQ section did not adequately differentiate students, therefore for the main study I decided not to continue using MCQ's and a large population, but instead to combine a short open-response written test with Piagetian-type task interviews, in order to observe students solving problems. In this way students' perceptions about the concepts under study could be progressively explored if necessary. The written test data would act to validate oral data observations, similar to Laurendeau and Pinard (1962). All task interviews were tape-recorded and transcribed verbatim.

Several points had to be considered in using interviewing. The 'art of interviewing' and the need to develop an atmosphere of trust and mutual respect has been thoughtfully described by Simons (1976/77). Parlett and Hamilton (1972) highlighted the importance of the total context in its effect on student learning. Their work influenced my research development in several ways:

a) the value of being able to work within the subject and context of the student's course, resulted in high intrinsic interest in the tasks and written problems,
b) ways of reducing the potentially threatening 1:1 cross-examination of individual interviews were considered. I designed visual material to accompany every task. Some of these were an essential part of the problem; all were extremely successful in reducing student shyness or lack of confidence, and gave them a specific point on which to concentrate.

c) 'Illuminative' evaluation of educational research focused on important issues arising out of observations and other relevant data collection, rather than reporting achievement-based outcomes. Many ideas put forward by Parlett were paralleled in my interest in students' perceptions of the problems and underlying concepts, rather than merely the frequency of 'right answers'. However by just describing the issues, an overall picture of their relative importance may not always be clear, i.e. their frequency in the population. Related to this was the problem of sampling errors. In-depth interviews cannot be carried out on the number of students that allow statistical tests of significance. In any case statistics has as its fundamental assumption, a random population, and a small tertiary population could not be considered to be 'random'. The problem of frequency and sampling errors was reduced by including the entire first-year student population of the Human Biology Department at the University of Surrey, in the main Stage 2. These students are described in more detail in 2.7 below. Further relevant aspects of educational research were also considered. d) Clarity and completeness of data reporting is one of the most serious criticisms which I level at much research in education. Researchers have rarely documented precise phrases used in key questions of interviews — yet these may have been quite significant in 'cueing' students. Even in the most open interview the interviewer inevitably has contributed something — to ignore it does not
eliminate its possible effects. Piaget's meticulous vivid first-hand documentation of his studies was an example which influenced my own reporting of data, both input, and observations.

e) Many recent reports of tertiary students' learning do not document the sex of students. Until it can be demonstrated that sex is not a variable in a particular case-study, this again constitutes incomplete data reporting. Post-adolescent sex differences in spatial ability ($O^+ > Q$) and verbal ability ($Q > O^+$) have been widely accepted (Maccoby and Jacklin 1974, Tavris and Offir 1977).

f) Several studies have used paid volunteers. While this undoubtedly increases the participation rate, this practice should be used as conservatively as possible, for it alters the project from research into a business relationship, and reliability and validity of observations may suffer. None of the students in this project, either in the pilot or main studies, received any financial payment.

The complete set of problems in the written test and the task interview are contained in Appendices IV and V respectively.

For each of the three main concepts under study, several problems (both written and oral) were designed. Detailed analysis of these problems is contained in the relevant chapters — I have summarized the three basic concepts and the related problems in Table I. Their relationship to the overall concept of evolution is shown on the concept map, Appendix II, (drawn according to Ausubel's hierarchy of concepts 1968, also described in detail by Gibbs 1974).

**Source and validation of problems**

**A. Written test.**

<table>
<thead>
<tr>
<th>Question content</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.1 Insecticide - OR</td>
<td>Stage 1 (x 70)</td>
</tr>
<tr>
<td>A.2 Dinosaur</td>
<td>Renner (U.S.A.x 88)</td>
</tr>
<tr>
<td>A.3 Linear time-scale</td>
<td>MB — following discussions with CJT</td>
</tr>
<tr>
<td>Question content</td>
<td>Source</td>
</tr>
<tr>
<td>------------------</td>
<td>--------</td>
</tr>
<tr>
<td>A.4 Antibiotics</td>
<td>Stage 1 (x 70)</td>
</tr>
<tr>
<td>A.5 Fire</td>
<td>Modified from Piaget (1973)</td>
</tr>
<tr>
<td>A.6 Mars</td>
<td>MB</td>
</tr>
<tr>
<td>A.7 Insecticides</td>
<td>Stage 1 (x 70)</td>
</tr>
</tbody>
</table>

### B. Task interview

<table>
<thead>
<tr>
<th>Question content</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.1 MCQ experience</td>
<td>Stage 1 (x 70)</td>
</tr>
<tr>
<td>B.2 Concepts identification</td>
<td>Stage 1 (x 70)</td>
</tr>
<tr>
<td>B.3 Rock problem</td>
<td>MB, (untested)</td>
</tr>
<tr>
<td>B.4 Skin problem</td>
<td>MB - following discussions with CJT</td>
</tr>
<tr>
<td>B.5 Web problem</td>
<td>MB (untested)</td>
</tr>
<tr>
<td>B.6 Logarithmic time-scale problem</td>
<td>MB (see A.3)</td>
</tr>
<tr>
<td>B.7 Global future forecast</td>
<td>MB (modified from Toffler 1971)</td>
</tr>
<tr>
<td>B.8 Personal future forecast</td>
<td>MB (untested)</td>
</tr>
<tr>
<td>B.9 Rates of change graph task</td>
<td>MB (untested)</td>
</tr>
<tr>
<td>B.10 Effects of graph on society</td>
<td>MB (untested)</td>
</tr>
</tbody>
</table>

All questions were examined by the following independent biologists, before implementation of Stage 2.

1. C.J. TURNER (CJT) Senior Lecturer, Human Biology, University of Surrey.
2. DR. E. OLDFIELD Head of Science, West London Institute of Higher Ed.
3. DR. M. MARTIN Head of Science, Toorak State College, Victoria, Australia and Chelsea College London.

Dr. Martin commented that the Task Interview problems varied in level of difficulty, and considered B.3 and B.6 were the most difficult. This was not to be seen as a criticism of these questions.

All three expressed considerable interest in B.3 and other 'life' questions. In considering the questions on time-scales and rates of change, all three commented that it was both extremely difficult to 'teach' the concept of 'time' and to assess the understanding of it.
In the following summary I have listed the three main sub-ordinate concepts of Darwinian evolution (Appendix II) on which the problems were based.

Table I

<table>
<thead>
<tr>
<th>CONCEPT</th>
<th>WRITTEN TEST</th>
<th>TASK-INTERVIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Selection</td>
<td>A.1,7 Insecticides</td>
<td>B.4 Skin</td>
</tr>
<tr>
<td></td>
<td>A.4 Antibiotics</td>
<td>B.2 Concept identification</td>
</tr>
<tr>
<td></td>
<td>A.2 Dinosaur</td>
<td></td>
</tr>
<tr>
<td>Life</td>
<td>A.5 Fire</td>
<td>B.3 Rock</td>
</tr>
<tr>
<td></td>
<td>A.6 Mars</td>
<td>B.5 Web</td>
</tr>
<tr>
<td>Time</td>
<td>A.3 Linear time-scale</td>
<td>B.6 Log. time-scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.9 Graph of rates of change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.7 Future - 3 predictions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B.8 Future - personal forecast</td>
</tr>
</tbody>
</table>

Implementation of Stage 2.

Stage 2, the main study was implemented into two steps.

A. Written test. In the second week of Term 1, the written test replaced a normal course lecture. The senior lecturer introduced my project to the students and requested their full co-operation. He pointed out that it would not contribute to their assessment in their course, but that the Department was most interested in my results.
I reaffirmed that their answers would be completely confidential. I described the project as a study of their understanding of scientific concepts basic to the environmental changes and deterioration occurring today. Many of the problems had no single 'right' answer, the interest being in the approach to the problem.

B. Task interview. During the following three weeks I saw every student individually, and gave them further problems to 'reason aloud'. All interviews were tape-recorded, and averaged forty-five minutes per student. Utmost care was taken to ensure that each student was asked identically worded problems.

2.6 METHODOLOGY STAGE 3: LEARNING STYLES

(a) The two most common methods of observations on learning styles have been reading-comprehension tasks, and problems of modified Games theory. I was interested in developing biological problems which could be used to analyse for differences in 'style' or approach. The wording of several oral tasks was deliberately left as open as possible to allow students to talk freely. In all these problems, I did not interrupt the student in any way during their explanations, in order not to disrupt their natural style. Utmost care was given on these (and all) oral problems to ensure that students were all asked the identical problem. These have been recorded verbatim in the relevant chapters.

(b) An experimental visual-verbal translation task was also designed. It was a diagram of the main specialized cells in Immunity, (Appendix VI) again, a biological task of high intrinsic interest. The diagram was very carefully drawn so that it represented a balanced 'whole'.

I thank Mr. Clive Turner and Dr. Eileen Oldfield for their suggestions in the design and implementation of the Immunity task, including timing a full pre-test. Dr. Colin Young (Lecturer in Microbiology, Univ. of Surrey) confirmed the biological accuracy of the diagram. Dr. Diana Laurillard
Lecturer in Educational Technology, Univ. of Surrey) analysed sample protocols on Pask/Martonian criteria, which in turn enabled me to specify exactly the criteria used in my analyses of learning styles and levels of integration.

This task was given to the students as part of a 'report-back' session on their understanding of natural selection, which again replaced a normal course lecture in the last week of first term. Following this task, (which is described in detail in Chapter 8), I asked which students had previously studied this topic, (it was not part of the standard A-level syllabus).

(c) At the beginning of the second term the Human Biology students sat for an examination, which contained one essay question. A choice of three essays was offered, each was written in a very distinctive style. Two weeks after the exam, at the beginning of a normal course lecture, I repeated the three questions to the students and asked them to write down any reasons they could remember which influenced their choice. This provided data on the relative importance to students of 'content vs. style'.

All these observations on learning styles are reported in Chapter 8. Each set of observations was analysed separately, students were numerically coded throughout.

These various results were then tabulated to determine the overall consistency of style for individual students. A table summarized the frequency of styles observed.

In studying students' understanding of the concept of natural selection (Chap. 5) it was possible to group students into 'sound', 'partial' and 'poor' levels of understanding. (Table II Chap. 5). The students who had been classed as 'sound' and 'partial' in understanding were then identified on the learning style table, to determine any possible relationship between learning outcome (concept understanding) and style. This integration of the two components of this project is contained in Chapter 9.
2.7 STUDENT POPULATION — STAGES 2 AND 3

(a) Students

The entire 1978 first-year intake of the two courses of the Department of Human Biology and Health, participated in the main study, Stage 2. Details of age and sex are tabulated:

<table>
<thead>
<tr>
<th>Course</th>
<th>✔</th>
<th>♀</th>
<th>Age-range</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Biology (HB)</td>
<td>16</td>
<td>16</td>
<td>18-20 yrs, 6 x 22 yrs, 1 x 30</td>
<td>32</td>
</tr>
<tr>
<td>Nursing Studies (NS)</td>
<td>17</td>
<td>3</td>
<td>18-20 yrs.</td>
<td>20</td>
</tr>
</tbody>
</table>

Forty-five students (87%) had come to University immediately following their A-level exams.

In the Human Biology group, seven students had done previous tertiary studies. These were Nursing (2), Radiography (2), a part Open-University course (1) and one had five years Army experience. Only one student out of the 52 had not studied Biology at A-level, or its equivalent (HND, or overseas qualifications).

(b) Biological background

This has been described from two aspects, their A-level examination board, and their biological MCQ experience. (NB. Their A-level Biology results have been ignored throughout this project).

Examination Boards

These students came through a variety of A-level Examination Boards, with three (JMB, London and Cambridge) accounting for 65% of all students.

Table II follows.
Table II

<table>
<thead>
<tr>
<th>BOARD</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMB</td>
<td>5</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>London</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Cambridge</td>
<td>7</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Oxford</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Ox. &amp; Cam.</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>AEB</td>
<td>3</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Welsh</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Irish GCE</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>ILEA (HNC. OND)</td>
<td>4</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Overseas</td>
<td>3</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>32</td>
<td>20</td>
<td>52</td>
</tr>
</tbody>
</table>

**MCQ Experience**

As part of the A-level Biology exam, three Boards include an MCQ component (one and a quarter hours or twenty per cent). These are JMB, Cambridge, and Oxford, and account for fifty per cent of students. Two more Boards, London and Oxford-and-Cambridge, use MCQ as part of their O-level Biology exam, accounting for a further twenty-five per cent of students.

Of the remaining twenty-five per cent of students, all except two have experienced MCQ questions in several other subjects, particularly Chemistry, Physics and Maths. Several humanities subjects (Geography, History and General Studies, and all languages) also use MCQ.

Only two students (one overseas, one Welsh) had never seen this form of question. Overall in the 1978 intake into this Department, 75% of all students were familiar with biological MCQ.
2.8 METHODS OF ANALYSIS

I have used the same broad procedure in analysing both written test data and transcribed interview data in both Stage 1 and Stage 2. Students were numerically coded. Taking one problem at a time, the key ideas in the explanations of individual students were transcribed to a single line, on master sheets.

As an example of this method, I have included the 'key' of student No. 9 (main study), whose sound understanding of the concept of natural selection in the Skin problem has been recorded in 5.3, page 115

key:
'if darker 1st, lighter came later, presumably adv. mutation —
(NB. difficult in terms of reflection) — survival of the fittest'.

In Stage 2, this resulted in two master sheets (one for the 32 HB students and one for the 20 NS students), for each problem. It was then quite efficient to analyse the two groups of students for major ideas, or common criteria used in their explanation. This was facilitated by both the use of colours to underline common ideas, and symbols as margin-notations. In this way the frequency of ideas could be determined for each problem, and these results tabulated.

It should be noted that, by this method, the tables of results were developed after the major common ideas had been identified in students' explanations — they were not my pre-determined categories of answers. In describing the results of each set of problems I have placed the tables to give the greatest clarity of the results, rather than at the end of the results sections.

This transcription method, although initially laborious has proved thorough and enabled data to be quickly inspected for both perceptions and learning styles.

These tables have been used to show most clearly, the distribution of students into the various categories; and statistical analysis,
(apart from results in the pilot Stage 1) is inappropriate. A more detailed description of specific analyses is contained in each chapter of the results.

2.9 TERMINOLOGY USED IN THIS PROJECT

In reviewing the literature I have used the specific words that the various authors have themselves used. However this field is exploding with coined words and phrases. The goal of educational research is to clarify, not confuse, all who teach, but this gulf will not be bridged by 'intellectual jargon'. Wherever possible I have used the simplest and most common word in discussing this project. I have defined certain words of fundamental importance in this project:

CONCEPT: Ausubel has defined a concept essentially as an abstract classification, with no real existence. This latter phrase is an important distinction from a mere classification of objects (called 'concrete' concepts by some workers, see 1.3). In Ausubel's terms a 'house' is not a concept, it is a real object whose attributes may be clearly defined. The most precise concept associated with 'houses' would be, in my interpretation of Ausubel, 'shelter'. In this concept could be linked various 'shelters' such as houses, nests, warrens, etc., all of these being conceptually linked by the idea of a secure comfortable habitat from the external environment; i.e. by a functional or operational definition. It is in this sense that I have used the word 'concept' throughout this project; i.e. not what a concept is (an absolute definition), but what it does.

In this project I have extensively studied the concept of natural selection (which does not exist as an entity in the real world), using problems of natural selection at work.
Further discussion of Ausabel's hierarchy of concepts is contained in Chapter 10.5.

INTEGRATION:

The process of linking new concepts into an existing framework of knowledge. It corresponds to Piaget's 'assimilation' and Marton's 'deep-processing'. In the systems model of learning, proposed in the Preface, integration is represented by the '+' sign in the 'process' stage. The two levels of integration (low and high), identified in these studies is discussed in detail in 8.1.

LEARNING: (adj).

Has been used, where possible, instead of 'cognitive' for simplicity for teachers not familiar with this latter word.

LEARNING STYLE:

The distinctive way a student 'sees' (i.e. his perception of) a particular task or problem; essentially as a 'whole', or as a set of 'parts'. (In this it echoes some of the earlier Gestalt school of Psychology). Further discussion of the various dichotomies is contained in 8.1.

Synonyms are 'cognitive style', 'cognitive strategy', and 'learning style' may be considered an 'intellectual skill', (this latter point is discussed in Chap. 8). In the original systems model, learning style is included as the first step in the 'process' stage, as one of the intellectual skills involved in problem-solving. Detailed discussion of the number of different learning styles which have been identified in these studies, is contained in 8.1.

MEANINGFUL LEARNING:

A more precise term than the everyday word 'understanding'. The Oxford dictionary defines 'understanding' as: "having
insight or good judgment, the power of abstract thought, perceiving the meaning of”.

According to Ausubel and Wertheimer, meaningful learning or productive thinking is when a student can re-organize a previously learned concept and translate it successfully to a new, or unfamiliar situation.

In the systems model, proposed in the Preface, meaningful learning corresponds to 'outcome'.

I have used an unfamiliar problem-solving approach in this project. For each concept studied, several problems were designed. In such an approach:

**Sound** understanding described a student who consistently identified and correctly applied the relevant scientific concept on which all the relevant problems were based, (as has been shown in 2.5 these were not sequentially grouped).

**Partial** understanding was used to describe a student who was able to 'solve' (i.e. apply the correct concept) some, but not all the problems related to a particular concept.

**Poor** understanding was when students were unable to identify the correct concept for any of the relevant problems. Instead, these students identified only the topic, or content of the problem, (e.g. in the Insecticide and Antibiotics Problems (A.1 and A.4) these students identified 'chemicals in the environment' instead of 'natural selection'.) This correlates with Wertheimer's 'rote-memorizing', Ausubel's 'rote-learning' and Marton's 'surface-processing', and my own 'low level of integration'. (Chap. 8.9)
PROBLEMS AND TASKS:

In the main study, I have used both problems and tasks. A task was a more general term, which included anything that a student was asked to do (e.g. to describe a diagram). A problem was an instance of a concept in operation, which required a student to reason through or to explain. Some problems were convergent in the sense that there was a definite correct answer, some were divergent in the sense that there was no single correct answer, but several answers may be correct.

Finally, I would like to mention that with the exception of a small section in Chapter 7, this project has been devoted to cognitive aspects of learning, but this is not intended to suggest that I consider affective aspects of learning are unimportant. They are important aspects of learning, as I hope I have conveyed in describing the development of the task interviews (2.5). In the main study of this project the participating students were in the first term of their University life. I have not explored the 'hidden curriculum' (Snyder 1971) of this experience for these students.
STAGE 1. PILOT STUDIES
CHAPTER 3.

THE CONCEPT OF NATURAL SELECTION

The prime purpose in the pilot studies was to design and test problems which revealed the level of understanding, and the nature of any misunderstandings about the concept of natural selection, held by first year tertiary students. The design of the written test has been described in 2.2, it is included in its original form (the OR:MCQ order only), in Appendix III.

Analysis of these pilot studies is divided into several sections. The validity of these two common forms of questions — the short open-response (henceforth OR), and the multiple-choice question (MCQ) were compared in 3.2. These observations were then used to determine students' levels of understanding of this concept (as defined in 2.9), and these results are described in 3.3. Students' answers were further analysed for specific misunderstandings, in 3.4.

These overall results identified a very small number of students who had shown sound understanding of natural selection. I contacted these students again and individually interviewed them about problems in learning and experiences in teaching this concept, analysed in 3.5. These interviews provided preliminary data to further analyse in terms of 'learning styles' (Pask and Scott 1972), with which I had become familiar. This analysis is described in 3.6.

3.1 ANALYSIS OF THE PILOT PROBLEMS

P.1. Insecticides.
Both the change in the environment and the target population are clearly identified.

Only the change in the environment is named, the students have to identify the target population (bacteria).
P.3 Rabbits.

Neither are clearly identified - the change being the death of the host, the target population being the virus. The essential role of diversity, in both rabbit and viral populations must be understood in order to completely explain the two observations:

(a) why rabbit numbers are again increasing;
(b) why the present virus is less virulent than the original strain.

In the MCQ versions of these problems the distractors were designed not only to test for understanding, but also to reveal specific misunderstandings:

- the origin of mutations (i.e. spontaneous or induced);
- an understanding of 'immunity' (acquired) and 'resistance' (inherited);
- the time-scale of environmental change;
- the relationship between 'adaptation' and 'natural selection'.

3.2 THE VALIDITY OF TWO FORMS OF ASSESSMENT QUESTIONS

Students' tests were numerically coded and their answers were examined. An ordinal scale of measurement was used in analysis. The key ideas of individual answers were extracted and transcribed on to master sheets. Correct explanations and MCQ answers were each allocated 1 mark, resulting in a possible maximum of 3 marks for each of these sections. (percentages shown in brackets)

Results of the Open-Response Section (OR).

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TOTAL POPULATION</td>
<td>32 (51)</td>
<td>17 (27)</td>
<td>7 (11)</td>
<td>7 (11)</td>
<td>63 (100)</td>
</tr>
<tr>
<td>2. BIOLOGY STUDENTS</td>
<td>21 (43)</td>
<td>15 (31)</td>
<td>6 (12)</td>
<td>7 (14)</td>
<td>49 (100)</td>
</tr>
<tr>
<td>3. NON-BIOLOGY STUDENTS</td>
<td>11 (79)</td>
<td>2 (14)</td>
<td>1 (7)</td>
<td>0</td>
<td>14 (100)</td>
</tr>
</tbody>
</table>

Graph I shows these results.
Results of Multiple-Choice Section (MCQ)

In the MCQ section there was a chance error due to random guessing, (students were not penalized for an incorrect choice). Since there were 4 alternative answers in each question, the maximum possible chances for a correct guess were 1 in 4, and 1 in 16 for 2 correct guesses. (The possibility of 3 correct guesses, 1 in 64, was beyond the limits of the population size).

In order to correct for the maximum possible errors due to random guessing, the following corrections were made to the final results (percentages shown in brackets).

<table>
<thead>
<tr>
<th>MCQ Correction.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. TOTAL POPULATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td>15</td>
<td>21</td>
<td>18</td>
<td>9</td>
<td>63</td>
</tr>
<tr>
<td>If 1 in 4 guess X1</td>
<td>-5</td>
<td>-4</td>
<td>-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If 1 in 16 guess X2</td>
<td>20</td>
<td>16+4=20</td>
<td>14+2=16</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Corrected results</td>
<td>21 (33)</td>
<td>20 (32)</td>
<td>15 (24)</td>
<td>7 (11)</td>
<td>63 (100)</td>
</tr>
<tr>
<td><strong>2. BIOLOGY STUDENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td>10</td>
<td>16</td>
<td>14</td>
<td>9</td>
<td>49</td>
</tr>
<tr>
<td>If 1 in 4 guess X1</td>
<td>-4</td>
<td>-3</td>
<td>-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If 1 in 16 guess X2</td>
<td>14</td>
<td>12+3=15</td>
<td>11+2=13</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Corrected results</td>
<td>15 (31)</td>
<td>15 (31)</td>
<td>12 (24)</td>
<td>7 (14)</td>
<td>49 (100)</td>
</tr>
<tr>
<td><strong>3. NON-BIOLOGY STUDENTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw score</td>
<td>5 (36)</td>
<td>5 (36)</td>
<td>4 (28)</td>
<td>0 (0)</td>
<td>14 (100)</td>
</tr>
<tr>
<td>Corrected results</td>
<td>6 (43)</td>
<td>5 (36)</td>
<td>3 (21)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Graph II compares these correct MCQ results for (1) total population (63), (2) biology students (49), and (3) non-biology students (14).

Individual students' results in the OR and MCQ section, (uncorrected for guessing), were then combined to give a maximum possible result of 6.

Graph III shows the overall results for both the total student population, and the biology students.
Graph I. OR Section.

Graph II. MCQ (corrected) Section.

key:
- Total population
- Biology
- Non-biology
### OR + MCQ (uncorrected) RESULTS OF THE TWO SECTIONS COMBINED

<table>
<thead>
<tr>
<th>LEVEL OF UNDERSTANDING</th>
<th>POOR</th>
<th>PARTIAL</th>
<th>GOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TOTAL POPULATION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>41 (65)</td>
<td>13 (21)</td>
<td>9 (14)</td>
</tr>
<tr>
<td>2. BIOLOGY STUDENTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>29 (59)</td>
<td>11 (23)</td>
<td>9 (18)</td>
</tr>
<tr>
<td>3. NON-BIOLOGY STUDENTS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>12 (86)</td>
<td>2 (14)</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>63</td>
<td>49</td>
<td>14 (100)</td>
</tr>
</tbody>
</table>

Graph III. OR + MCQ (uncorrected) COMBINED.

**key:**
- Total population: 
- Biology: 
- Non-biology:
The three graphs show:

1. Both MCQ and OR formats clearly discriminated the group of students with sound understanding.

2. OR further graded students, creating a second group with very good understanding, and a very large group with poor understanding. MCQ did not differentiate further, and randomly distributed other students.

3. OR specifically placed all non-biological students into the group with least understanding. MCQ distributed non-biological students into all groups except the very top group.

4. MCQ and OR combined for each student (Graph III) gave a more detailed ranking of concept understanding.

5. Taking OR and MCQ combined as the basis of 'degrees of understanding', 14% showed sound understanding and 65% very poor understanding, in the total population.

6. Among students with an A-level Biology background, 18% showed sound understanding, 23% partial and 59% very poor understanding of the concept of natural selection.

**DISCUSSION**

These results are based on quite a small number of students (63), and care should be taken against overinterpretation.

It may be cautiously concluded that, of the 2 sections, the OR section, where students had to write their own answers to the questions, yielded much more information about their real understanding of this concept. Further analysis of this OR section is contained in 3.3 and 3.4.

However the MCQ section appeared to be equally valid at detecting the best students. It should be pointed out that the distractors contained in these MCQ were derived from students' own phrases in free essays. These
MCQs had been tested on other students both before and after studying evolution.

These results suggest that a set of reliable MCQ may be quite adequate for a straightforward achievement test. Open-response questions are required for diagnostic or evaluative assessment. A more detailed picture is gained from a combination of these 2 assessment methods.

3.3 THE DETERMINATION OF THE LEVEL OF CONCEPT UNDERSTANDING

Method of Analysis

Taking each of the 3 questions individually, all students' written explanation (OR) and MCQ choice for the same question were transcribed into 2 columns. Thus from this stage neither the order of the test (i.e. OR/MC or MC/OR), nor the students' answers to other questions was known.

The 2 columns were then scored separately a + sign being given for a sound explanation on the designated MCQ, and a - sign against an unsound explanation or incorrect MCQ.

<table>
<thead>
<tr>
<th>MCQ</th>
<th>OR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) Thus a student who selected the correct MCQ, and wrote a sound explanation: + +

(2) A student who selected the correct MCQ, but gave an unsound explanation: + -

(3) A student who selected the wrong MCQ, and verified his misunderstanding: - -

(4) A student who selected the wrong MCQ, but for inconsistent/novel reasoning: - ?

Each of the 3 questions was analysed in this way, then the results were combined in tabulation form, showing individual student's overall performance.
The 4th (and to a lesser extent the 2nd) group pointed a way to a further stage of analysis. Answers to each of the questions which showed inconsistent or novel reasoning relative to their MCQ choice were marked on the master table with a red dot. This led to a categorization of 'degrees of understanding', ranging from the top group - those with 3 MCQ correct & 0 inconsistent explanations, - to the weakest group - those with 0 MCQ correct & 3 inconsistent explanations - with several intermediate groups.

RESULTS

Tables IV - VI show (a) the performance of students on the MCQ section for both groups, together with (b) examples of the 4 different types of OR/MCP consistencies already described, for each question.

In section (b) the right-hand column denotes the 1st section the student answered in the test (OR or MC). Non-biology students are identified with a minus sign (-) on the left. In group 4, where the choice of MCQ was inconsistent with the OR explanation, the appropriate MCQ choice is shown in brackets on the right.

Table IV. RESULTS OF MCQ AND OR CORRELATIONS. P.1. INSECTICIDES

<table>
<thead>
<tr>
<th>(a) MCQ Results</th>
<th>OR/MC</th>
<th>MC/OR</th>
<th>TOTAL</th>
<th>(Statistical analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>*B</td>
<td>20</td>
<td>11</td>
<td>31</td>
<td>.... (p = 0.49) (r = 0.1)</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>5</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>23</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

(b) OR Results

1. Correct MCQ, Sound Explanation. Order of test MC

'20 years ago, mutant insects existed which were not killed by insecticides. So though a large proportion of population was killed, a few individuals remained alive and were not affected. These multiplied rapidly and their gene mutations were passed on to offspring. Today these mutants thus make up a larger proportion of the fly population than they did 20 years ago.'

* denotes correct alternative
2. Correct MCQ, Unsound Explanation.

'Insects which came into contact with insecticides but which weren't killed eventually developed a form of resistance against the substance. The resistance developed and became stronger over the years and some flies now are immune to insecticide. Its development over years suggests that immunization is passed on genetically from one generation to next.'

'Nature has endowed creatures with ability to survive in conditions which were once unfavourable. This form of resistance reduces the efficiency of hitherto effective insecticides.'

3. Incorrect MCQ, Consistent Explanation.

A. 'Insects which did not get a fatal dose, though they did receive some, produced antibodies against the insecticides which were passed on to their offspring, and thus the presence of, or ability to produce antibodies against insecticides has increased over generations.'

C. 'Initial spraying of insects caused them to die because they were unused to the effects of the aerosol. However, as with most living organisms, the mosquitoes "adapted" to this spraying of poison on them by creating a different strain of mosquitoes which were in generations to come not affected by further spraying. Hence a much smaller population of insects die on spraying now, than when the aerosol was first used.'

D. 'This is because a mutation has developed due to earlier spraying and this is resistant to insecticides.'

4. Incorrect MCQ, Inconsistent/Novel Explanation

D. 'This is because original sprayings caused mosquitoes to build up a resistance to drugs and so it became less effective.'

D. 'Perhaps due to natural selection, those insects which survived were less affected by insecticides and so survived in order to produce progeny which were as resistant, and so those not resistant to insecticides were killed off and not allowed to breed.'

C. 'Genetics is main reason and immunity. Insects were not able to find correct antibody to combat the antigen but with passing of time bodies have produced correct antigen. The information of what this antigen is has been passed on to offspring resulting in the fact that today's mosquitoes are immune to sprays.'

D. 'When insecticides were first sold they were highly concentrated and this had the effect of killing a high proportion. But I think that this concentrated substance had some bad effects on humans. Insecticides used today are not very concentrated and small amounts of it, if it enters the body, produce no serious harm.'
Table V. RESULTS OF MCQ AND OR CORRELATIONS. P.2. ANTIBIOTICS

<table>
<thead>
<tr>
<th></th>
<th>OR/MC</th>
<th>MC/OR</th>
<th>TOTAL</th>
<th>(Statistical Analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) MCQ Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>9</td>
<td>4</td>
<td>13</td>
<td>...(p = 0.54) (r = 0.32)</td>
</tr>
<tr>
<td>* C</td>
<td>24</td>
<td>10</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>23</td>
<td>63</td>
<td></td>
</tr>
</tbody>
</table>

(b) OR Results

1. Correct MCQ, Sound Explanation.

'In beginning viruses causing infections were mostly of the type that were killed by antibiotics. So antibiotics destroyed them leaving the resistant strains to flourish. Administration of more antibiotics killed off the same but greatly increased the survival rate of the rest so that antibiotics are now becoming useless.'

2. Correct MCQ, Unsound Explanation.

'Drugs are dangerous even if taken in small amounts. Larger and persistent use is going to firstly reduce effectiveness of drug, and secondly bacteria may mutate leaving antibiotic ineffective.'

(-) 'Because if antibiotics are used for treating minor illnesses, the germs causing these diseases may develop into much more serious sources of disease, with greater immunity.'

'When treating minor illnesses, only small amounts of antibiotics are used. These small amounts may be enough to start a gene mutation of bacteria under attack, so that an immunity to antibiotic may occur. Hence patient will be more immune to treatment by same antibiotic in a more serious infection.'

3. Incorrect MCQ, Consistent explanation.

B. 'When major illnesses occur, antibiotics will be less effective.'

A. 'Increasing use of antibiotics for minor illnesses leads to their being less effective as body builds up an immunity against them. This leads to their being less effective when major illnesses are involved, where death is possible.'

* denotes correct alternative

B. 'Due to biological factors a species can become immune to antibiotic. Hence if strong antibiotic is used in treating minor illness, then in time the user becomes immune to the antibiotic. If at a later date a more drastic need of a strong antibiotic arises, the latter may not be available.'

A. 'One reason is the killing of microorganisms within the body that help us in some way, e.g. in digestion. Elimination of this symbiosis would have detrimental effect.'

D. 'Body will eventually get used to antibiotic, and produce antibodies, etc. to act against any future dose, so they will no longer be affected.'

D. 'In case the body, through posterity, develops immunity.'

B. 'Repeated use of penicillin results in natural selection of virus occurring, resulting in a much greater proportion of viral population becoming immune to drug, reducing effectiveness.'

Table VI. RESULTS OF MCQ AND OR CORRELATIONS. P.3 RABBITS

<table>
<thead>
<tr>
<th>(a) MCQ Results</th>
<th>OR/MC</th>
<th>MC/OR</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>22</td>
<td>11</td>
<td>33</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>* D</td>
<td>12</td>
<td>8</td>
<td>20</td>
</tr>
</tbody>
</table>

(b) OR Results

1. Correct MCQ, Sound Explanation.

'Population of rabbits which encountered the original virus died off, leaving isolated rabbits which only encountered a mutated form (of virus). For the pure chance of the mutation factor inherent in all organisms which survive was the rabbits which had the most resistance to the virus, which encountered the weak virus survived. Hence the virus survived as well as the rabbits multiplying.'

Partially Sound Explanation.

'These observations illustrate that the virus had varying resistance from the rabbits. Rabbits that had no resistance died out, did not reproduce and so did not pass on their genes. However, ones with resistance could overcome the virus, reproduce, and so their resistant gene would be passed into the next generation, showing survival of the fittest. This gene would be inherited, of course, and so the myxomatosis would not be fatal.'

* denotes correct alternative
2. Correct MCQ, Unsound Explanation.

'The rabbits adapt to environment where virus is present, by the virus chose the stronger type of rabbit to arrive.'

'Initially the virus was extremely potent and it destroyed the rabbit population, which meant it had destroyed its own environment. Thus by the time the rabbit population had increased again the virus had a long wait secluded from its natural environment. This seclusion led to the decline in the virus potency.'

3. Incorrect MCQ, Consistent Explanation.

(for A and C answers only, B answers shown in Table VI (a))

A. 'The remainder of the virus is only a mutant strain. This new strain is not very virulent due to this mutation. But there may be successive mutations that result in the increase of the virulence of the virus.'


A. 'Initially rabbits were not resistant to virus and so that many died - however later a resistance was built up by rabbits to combat this virus.'

C. 'Some of the rabbits would have an immunity to the virus, these animals would reproduce to give offspring with the same immunity and so the population of immune animals would increase.'

A. 'The rabbits have formed some immunity against virus. The fact that rabbits now tend to stay out of burrows more and hence keep out of the way of infected rabbits, tended also to stop the disease spreading so rapidly.'

A. 'The rabbits flourished because the food supply was in excess of the initial population needs. The rabbits thus reproduced and the population increased. The original myxomatosis was toxic to the rabbits and killed large numbers, but the virus changed (mutated or evolved) such that it was no longer toxic to the rabbits.'

Table VI (a).

<table>
<thead>
<tr>
<th>RESULTS OF 'B' MCQ AND OR CORRELATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. 3 RABBITS</td>
</tr>
</tbody>
</table>

1. B. MCQ, Partially Sound Explanation.

'The natural resistance of the rabbits for survival is causing the strongest rabbits to survive, thus defeating the virus, hence the progeny of this rabbit could probably also defeat the virus, hence the stronger strains were gradually eliminated as natural selection favoured the rabbits able to defeat the virus.'
2. B. MCQ, Consistent Explanation.

'Mutation probably occurred in the genetic population and so allowed some rabbits to resist such a disease and so multiply, but passing on modified virus as a result of mutation.'

'Rabbits could have built a partial resistance to the disease, producing an antitoxin.'


B. 'Myxomatosis tends to lose its effectiveness or "strength" as it is transmitted by carriers of the disease.'

B. 'Some things have happened inside the rabbits. The results of these happenings is to decrease the strain caused by the myxomatosis virus.'

B. 'The rabbits over the years reproduced (at their alarming rate) and the initial virus given became less and less fatal through each generation. Thus with each generation the virus became both milder and rabbits became immune to it, thus their number grew to the initial size again. Perhaps antibiotics within the rabbits' system reduced the virus to a mild one until the effects were not fatal, in an adaptive way.'

It is clear that all 4 types of explanations occurred in both the OR/MC order and the MC/OR order.

Table VII tabulates the actual number of students in each group, for each question.

The circles distinguish sets of results where the order of test has caused a marked difference.

Statistical Analysis of Table VII.

Independent Statistical Analysis, using two-way contingency tables, demonstrated a significant association between the order of presentation and the OR response ($r = 0.5$) in P.1. This was irrespective of whether the MCQ was right or wrong. A similar trend ($r = 0.2$) was observed in P. 2 and P. 3.
### Table VII (a)

**ANALYSIS OF RELATIONSHIP BETWEEN MCQ AND OR EXPLANATION**

**Q.1 INSECTICIDES**

<table>
<thead>
<tr>
<th>Type of Reasoning</th>
<th>Correct MCQ</th>
<th>Incorrect MCQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound</td>
<td>18</td>
<td>14</td>
</tr>
<tr>
<td>Unsound</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Consistent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inconsistent/novel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Correct MCQ 18 With sound reasoning
   - OR:MC 9
   - MC:OR 9

2. Correct MCQ 13 With unsound reasoning
   - OR:MC 11
   - MC:OR 2

3. Incorrect MCQ 14 With consistent reasoning
   - OR:MC 7
   - MC:OR 7

4. Incorrect MCQ 18 Inconsistent/novel reasoning
   - OR:MC 13
   - MC:OR 5

### Table VII (b)

**ANALYSIS OF RELATIONSHIP BETWEEN MCQ AND OR EXPLANATION**

**Q.2 ANTIBIOTICS**

<table>
<thead>
<tr>
<th>Type of Reasoning</th>
<th>Correct MCQ</th>
<th>Incorrect MCQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Unsound</td>
<td>23</td>
<td>15</td>
</tr>
<tr>
<td>Consistent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inconsistent/novel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Correct MCQ 11 With sound reasoning
   - OR:MC 7
   - MC:OR 4

2. Correct MCQ 23 With unsound reasoning
   - OR:MC 17
   - MC:OR 6

3. Incorrect MCQ 14 With consistent reasoning
   - OR:MC 9
   - MC:OR 5

4. Incorrect MCQ 15 Inconsistent/novel reasoning
   - OR:MC 7
   - MC:OR 8

### Table VII (c)

**ANALYSIS OF RELATIONSHIP BETWEEN MCQ AND OR EXPLANATION**

**Q.3 RABBITS**

<table>
<thead>
<tr>
<th>Type of Reasoning</th>
<th>Correct MCQ</th>
<th>Incorrect MCQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound</td>
<td>12</td>
<td>24</td>
</tr>
<tr>
<td>Unsound</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Partially sound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inconsistent/novel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Correct MCQ 12 With sound reasoning
   - OR:MC 7
   - MC:OR 5

2. Correct MCQ 8 With unsound reasoning
   - OR:MC 5
   - MC:OR 3

3. Incorrect MCQ 19 Partially sound reasoning
   - OR:MC 9
   - MC:OR 10

4. Incorrect MCQ 24 Inconsistent/novel reasoning
   - OR:MC 19
   - MC:OR 5
These tables show:

1. Students with good understanding of natural selection (by the OR) answered the MCQ correctly, irrespective of the order.

2. Students whose explanation was consistent with their choice of MCQ also were unaffected by the order.

3. When the explanations in the OR section were unsound or inconsistent, the order of presentation affected the OR score (significant to $r = 0.5$) in P. 1; similar trend ($r = 0.2$) occurred in P. 2 and P. 3. These differences are circled in Table VII.

DISCUSSION

The number of inconsistencies was both surprising and disturbing. It could suggest that these students are unable to conserve a formal concept for the duration of the test (approx. 20 mins. lapsed between the same question in the OR/MC order, less in the reverse). The evidence in this test is too slight to state whether these students have reached the stage of formal operations in their intellectual development, but this point is of interest in the light of Piaget's amended age-range (Piaget, 1972). It is also in line with Renner's observations on American college students (Renner, 1977). Further testing would need to be done to substantiate this point.

The narrower range and smaller number of novel answers in the MC/OR group compared with the OR/MC strongly suggested that the MCQ alternatives 'cued' to some extent the explanation given in the corresponding OR section. For this reason this group size was left at 23, and all further students received the OR/MC ordered test.

Further Comments on Results of Individual Problems

P.2 ANTIBIOTICS

An unusually large number of students, scoring an incorrect MCQ, showed inconsistent/novel OR explanations after they had done the MCQ.
This was almost totally due to their complete misunderstanding of the action of antibiotic drugs. The majority of these students failed to identify the target population for the drug (bacteria), and revealed not only considerable confusion between immunity, resistance and tolerance, but also serious misunderstanding of the laws of inheritance. (We do not inherit acquired immunity, or somatic mutations).

The word 'drug' seemed to side-track students away from the specific question and on to the action of drugs on the human system. The time-worn plea by teachers to 'answer the question which is asked', applies as much to objective questions as to the traditional essay.

P.3. RABBITS Table VI and VI (a)

By traditional criteria this question in the MCQ format was a poor question, with a greater percentage of students marking one of the incorrect responses (33 students marked B; 20 marked D, the most correct answer.)

Table VI (a) further shows that at least 1 B student had partially understood the role of natural selection in this question. However the majority of those who marked B revealed in their OR explanation the most common misunderstanding in this test, namely that:

'immunity is achieved in response to a change in the environment, which protects the individual from that change, and that this acquired/induced immunity is passed on to the next generation.'

This question could also be criticized for requiring further biological knowledge (on virus reproduction). I accept this criticism. I found it impossible to draft a question testing this degree of evaluation of natural selection without involving additional knowledge.

In this question, very few students adequately accounted for all the observations, in both the increase of the rabbit population and the
occurrence of the less virulent strain of virus. In scoring this OR question numerically, ½ mark was given for either partial explanations.

The final results of the test as a whole demonstrate convincingly that this question did discriminate the top students. This was its prime purpose.

It is worth noting here however that if this study were repeated, I would, (a) re-word the distractor B in MCQ 3 to read:
'B. 'The rabbits became immune to the virus.'
and (b) re-word the the stem of MCQ3 to include both observations:
'These observations may best be attributed to:'

3.4 ORIGIN AND NATURE OF MISUNDERSTANDINGS

Methods of Analysis

The preceding sections resulted in students being graded in two ways:
From SECTION A, by numerically scoring the answer in each of the two parts of the test from 0 - 3, and combining these figures for each student to a possible maximum of 6;
From SECTION B, by adding the number of correct MCQ to the number of inconsistencies within the test.

Both methods resulted in almost identical groups. Since the identification of inconsistency was on a limited evidence, the numerically-derived groups from SECTION A was used in further analysis.

As has already been described, the OR section contained a fourth question:

Q.4. What basic concepts or principles are contained in these 3 questions?

This question was not used in classifying students, but to further test the ability of students to identify the relevant concepts.
The three groups of students (total 63), ranked from (1) sound understanding (\(\frac{5-6}{6}\)), (2) partial understanding (\(\frac{3-4}{6}\)) and (3) poor understanding (\(\frac{0-2}{6}\)), were then tabulated and the concepts they had listed in Q.4 were transcribed. Table VIII (p. 81) contains these complete lists, with unsound concepts or misunderstandings underlined. The right-hand column shows those students with no Biology background (-), and also shows those students who received the test in the order MCQ:OR.
### TABLE VIII. CONCEPTS ANALYSIS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-)</td>
<td>On the right indicates no A-level biological background.</td>
</tr>
<tr>
<td>MC</td>
<td>On the right shows those 23 students who received the order MC/OR misconceptions are underlined</td>
</tr>
</tbody>
</table>

#### GROUP 1 - SOUND UNDERSTANDING (5-8/6)

Resistant individuals already exist before environment changed and then selected for survival by natural selection.  
Natural selection. Only those that can fit into environment will survive.  
Natural selection. Gene mutations with selective advantage give rise to new strains.  
Genetics in nature. Natural selection. Genetic equilibrium.  
Populations are not made up of genetically identical individuals.  
Natural selection. Basis of natural selection - destructive characteristics are filtered out, only 'strong', i.e. adapted survive and reproduce.  
Genetic theory of evolution - each individual is different in some way, species are always changing, so over millions of years have evolved.

#### GROUP 2 - PARTIAL UNDERSTANDING (3-4/6)

Immunity of a species caused by genetic recombination leading to mutation - most successful mutant is most suited to its environment.  
Natural selection, chance mutations, inheritance, economics (drug industry).  
Survival, immunity, effects of chemicals.  
Organisms can put up a resistance to something that threatens their life.  
Natural selection, genetics.  
Animals adapt and become used to certain types of surroundings, thus becoming immune from certain things.  
Darwin's concepts of origin of species, fittest survive, i.e. healthy or most adapted.  
Diseases can be stopped by factors already in body. All antibiotics will become useless as bacteria will become immune to them.  
Resistance to disease either natural, or developed as a result of mild disease, which can be passed genetically on.  
Immunity to disease over time. Form of Q. leads one to present his own opinion on subject in best way he can.

#### GROUP 3 - POOR UNDERSTANDING (0-2/6)

Genetical change through adaptation to changing environment, becoming better suited to new environment.  
Darwinian evolution, species are already adapted to survive and reproduce offspring with this characteristic (but in Q.3 it is not rabbit but virus mutating to become less toxic).  
1. Natural selection. 2. Overprescription dangerous. 3. Hybridization, etc.  
Man interfering with the environment. Animals can develop resistance.  
Organisms build up resistance to initially harmful chemicals.  
Ability of animals to resist harmful stimuli and adverse conditions.  
Immunity against disease. Antibiotics.  
Man-made drugs and poisons can have initial effect but constant use results in immunity and therefore no use.  
Man's efforts to control natural elements, and struggle to find new methods of control as old ones become nullified by natural resistance.  
Development of resistance to poisons, therefore increased doses have to be given. For man the danger of increased doses of medicines.  
Growing resistance to predators. Knowledge and application of science far from complete. Mutations.  
Mutations of strains or species. Build-up of antibiotics, hence immunization.  
Any living creature will modify its body structures to decrease the strain added on itself. Development of adaptation of insects and viruses to changing environment. Adaptation process develops over a period.  
Capability of a species (virus, rabbit, insect) to change in order to survive.  
Immunity to illness carried in antibodies in blood and passed on to future generations which are then unaffected by same disease.  
Immunity and its development. Dangers of antibiotics.  
Diminished effects of antibiotics and why.  
Genetic change due to adverse conditions. Adaptation of organisms to previously adverse conditions.  
We should control the use of drugs to overcome biological imbalance, yet prevent human organism becoming immune - Heredity and genetics. To drug.  
General principles of evolution.  
Proper use of drugs. Advantages and disadvantages of medicine.  
Mutations occurring in organisms, giving rise to better survival in the environment.  
Evolution and adaptation to surrounding environment.  
Not specific enough, don't know.  
Genetically inherited immunity, decreased virulence of introduced viruses.  
Initially desired results, but over years effectiveness reduced due to mutation (and resistance may be built up, etc)  
Adaptation to environment, resistance, passing on of genetic material, genetic mutations.  
Initially affected by change in environment, but continual exposure causes some form of immunity to disease, or a change causing less harm to human population. Dangers of trying to kill pests, ways they adapt to foil man.  
Adaptation by all living things to changes in the environment.  
Explanations of various happenings, why and what other professional people explain the happenings.  
Animals can develop resistance to things introduced artificially.  
After exposure to drugs, creatures can, after some time, adapt and develop an immunity against drug.
DISCUSSION

These 'concepts identification' lists confirmed that the test problems had accurately and reliably placed students into groups ranked into levels of understanding. All students in the top group correctly identified 'natural selection' as the key concept underlying these problems, or explained the role of natural selection acting on individual variation.

In the group which had been classified as showing partial understanding, the first of the misconceptions occurred, namely the identification of 'immunity' and the 'development of resistance'. Major errors of basic genetics, e.g. that mutations are induced rather than occurring spontaneously, and that acquired immunity 'is passed on' occurred in this group also.

The frequency of misunderstandings increased in the group which had been classified as showing poor understanding, and they dominated these students' answers to this question. These lists revealed that students who identified 'adaptation' (which could be theoretically considered a relevant concept), were in fact using this term as a 'process of adaptation', i.e. Lamarckian evolution.

One of the most striking features of the concepts listed by students with poor understanding was their tendency to identify the topic, or content of the problem, instead of the underlying concept. Thus they listed 'the effects of, or immunity to, drugs and chemicals' as the common concept rather than recognizing that these three problems involved the application of natural selection 'at work'. This observation is essentially similar to Marton's 'surface-processing', i.e. seeing the content of the task, in contrast to 'deep-processing' which considers the underlying meaning.
THE STEPS IN UNDERSTANDING. The major steps leading to the process of evolution have been identified in Table IX.

From the analysis of the concept lists described above for the different groups of students, it was possible to draw a parallel "STEPS IN MISUNDERSTANDING, which is shown also in Table IX on the right side.

Table IX

<table>
<thead>
<tr>
<th>STEPS IN UNDERSTANDING</th>
<th>STEPS IN MISUNDERSTANDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SPONTANEOUS MUTATION—DIVERSITY IN POPULATION</td>
<td>1. ×</td>
</tr>
<tr>
<td>2. A CHANGE IN THE ENVIRONMENT</td>
<td>2. A CHANGE IN THE ENVIRONMENT</td>
</tr>
<tr>
<td>3. INDIVIDUALS WITH SUITABLE CHARACTERISTICS SURVIVE BY SELECTION</td>
<td>3. INDUCES MUTATIONS</td>
</tr>
<tr>
<td>4. CHARACTERISTICS ARE INHERITED</td>
<td>5. WHICH ADAPT ORGANISMS TO ADVERSE CONDITIONS (BECOMING 'IMMUNE')</td>
</tr>
<tr>
<td>5. OVER GENERATIONS POPULATIONS BECOME BETTER ADAPTED TO THIS NEW ENVIRONMENT</td>
<td>4. THESE ACQUIRED CHARACTERISTICS ARE PASSED ON</td>
</tr>
</tbody>
</table>

SUMMARY:

BY NATURAL SELECTION, A POPULATION EVOLVES TO BECOME ADAPTED TO CHANGE

BY ADAPTATION A SPECIES EVOLVES TO BECOME IMMUNE TO CHANGE

DISCUSSION

Comparison of these 2 diagrams clearly shows the development of misunderstanding of Darwinian evolution, held by the majority of students tested.

The misunderstanding steps represent an extension of the Lamarckian view of evolution, which states that structures are developed/or lost on the basis of need.

Several important points emerged:
1. The absence of Stage 1, which, I believe, is the origin of misunderstanding.

2. The development subsequently of a THEORY OF ADAPTATION by induced immunity (of individuals) rather than the DARWINIAN THEORY OF EVOLUTION, by natural selection (in populations).

3. Serious errors in basic GENETICS (including the existence of spontaneous mutations, the laws of inheritance).

4. Considerable confusion between IMMUNITY and genetic resistance.

5. Ignorance of the action of ANTIBIOTICS in modern medicine.

6. A lack of appreciation of TIME, (one generation vs. many) and the time-scales of change in the biosphere.

### 3.5 INTERVIEWS WITH STUDENTS WITH SOUND UNDERSTANDING

Having identified such a small group, I was interested in why they were so far further advanced, conceptually, than the majority of their contemporaries. Their educational backgrounds showed a wide diversity: from 6th Form College to Grammar School to Technical College; their main texts varied, and their current courses were very different.

This section contains an analysis of individual, informal interviews with these students, approximately six months after their written test.

**Development of the Interviews**

The prime purpose of the interview was to explore the teaching and learning of these concepts experienced by these students at school.

It was essential to have the students talking freely. For this reason it was important that they should not feel that their understanding was still being assessed. Therefore, as an introduction, I told each of them that they belonged to this very small group, and asked if they were aware of this.

The two central questions followed.
1. Can you remember exactly how your teacher taught these concepts to you?

2. How would you go about explaining 'natural selection' to someone who has never heard of it before?

Of the 9 students, 7 were individually interviewed for up to 45 min. The remaining two students had already left London on vacation, but replied to a letter containing the questions, and requesting their spontaneous, written thoughts (i.e. not carefully pre-planned essays). The 3-4 page informal replies were as valuable as the transcribed interviews.

All interviews were tape-recorded.

METHOD OF ANALYSIS

As has been described (2.8) I prepared a 'master sheet', containing a 'skeleton' of key points made by each student during the interview. This enabled selection of criteria for analysis, and highlighted common features between students. It also facilitated choice of extracts from the original transcripts, included in this Chapter.

DISCUSSION

Three points emerged in analysis: (1) methods of effective teaching recommended by these students, (2) their own learning experiences, and (3) students' perceptions of the frequency of common misunderstandings.

(1) Effective teaching.

The most striking finding of these interviews was the consistent description of how the students would 'explain' this concept (Question 2). Their explanations were dominated by the use of examples. All 9 students mentioned the importance of examples. Most importantly, students recommended introducing the whole topic by an example, before any theory at all:

'I would never say "you were going to learn the theory of evolution" - they would switch off; it sounds as if it's going to be the ultimate concept, like Newton's Laws of Motion. I'd teach from examples and tell them later what it was.'
One student described the way she had already tried on her friends:

'I used "colds", to show that everybody's different - "how many do you get a year?" Then I gave the example of "what if there were only 2 people left in the world, due to a massive environmental change ... they'd be immune to everything."

The actual choice of example was important:

'Well, I wouldn't fall into the pitfall of classical genetics! The best way would be to use specific examples - well-publicised ones - for example, DDT and pesticides have been in the news a lot lately. (USA exchange student)

I asked him how he had found the teaching of evolution in his UK Human Biology course this year:

'Well, they used the development of teeth and the different area of grinding on molars if the environment was changing, favouring tougher grasses. It was a bit boring.'

he added. In the light of his emphasis on highly-publicised, important examples, this was hardly surprising. Another student drew out the use of examples for a different reason:

'The problem is not in the actual simple explanation, it is in applying the principle. Most people can see the difference between Lamarckian and Darwinian evolution, for example in giraffes; but I think this classic example is learnt rather than understood. Examples are a good method of trying to sort out various problems .... Probably drugs are a clear example. We did this in A-level, and it made more sense than the theoretical explanations of evolution.'

Two other students cited the peppered moth. One had used this example in a talk to a Church youth group. Another mentioned the giraffe as a 'very simple, yet easy to remember' example of survival of different individuals:

'I'd do a little example at the beginning - just mention the giraffe; then the theory, then explain the giraffe in more detail, with examples intermingled with the thing - at each stage you have a little theory till you build up into more.'

'Disease' was used to illustrate the explanation of another student (extract included in 3.6 - (2) the holist). (page 90)

The 9th student extended the use of examples to a most thoughtful application:

'I would take each piece of evidence and show how scientists believe they work. For example, the fossil record, in particular the example of the horse. Then direct evidence, (this might be difficult without any genetics knowledge), for example, selective breeding; I'd use cattle. And then the links, e.g. the platypus (reptilian and milk) and the kangaroo.'
I then asked this student whether she considered the use of antibiotics and bacteria a good example? After a moment's thought, she replied:

'It needs a knowledge of genetics, so you'd have to do that first and could get confused. It's unexciting, but probably the most important. I think I'd attempt to explain it after I'd gone through the horse, to then apply it on a microscale. The insect still looks the same, even though his resistance is different'.

Later in the interview this student made a most significant comment on the use of examples in teaching. She had been ruefully describing how she had not read all her 'reading list' books during the preceding year, but had picked out ones that sounded pertinent, and read bits of them. During the summer holidays she had read them all, with enjoyment, ('because I didn't have to read them'). I commented that this was a problem for all teachers, namely how to encourage students to read recommended wider literature. Her reply is a strategy which could be followed by all who find themselves in this position:

'It'd be better if they could give an example of the book (carefully chosen) - a few pages or even lines of what its actually like, how readable it is. Otherwise I tend to look at the book and think, "Crikey, I can't read that!" The length is also off-putting. But when you come to read them, some are very interesting, and are set out in language you can understand.'

I have included many individual quotes in this discussion. Their originality, and consistent lucid strategy of the use of examples, is an example in itself to all who teach.

(2) Teaching experiences

Students had excellent recall, explaining the introduction of the concept first at O-level and again at A-level. Several students mentioned their teacher's enthusiasm for this particular topic:

'Our teacher liked evolution - it was his favourite topic. He took examples of things to show the different evidence put forward, and it seemed to me to make sense all the way through. It was the 1st thing we did at A-level. We did the direct evidence, (peppered moths, ancient links, and geographic - Darwin's islands). Then we did the work of Lamarck, Darwin, neo-darwinism with the influence of Mendel, and then changed topics. We came back to it again later in
the year in Genetics, and tied it together.... for the class as a whole it was their favourite topic.'

Another reported:

'In A-level Genetics I was very, very interested. We even did the myxamatosis virus! (a reference to the original written test). It was the enthusiasm of my teacher which made it. I thought natural selection a very easy concept.'

Other students used phrases such as 'the long neck of giraffes was really drummed in', and 'we were indoctrinated with the peppered moth', indicating the emphasis teachers had placed on these examples.

It should be recorded that 3 of the 9 students had experienced a NUFFIELD A-level course, 2 Nuffield Biology and 1 Nuffield Physics. These students had vivid impressions of these courses and subsequent effectiveness for further studies. Their comments varied widely:

'In A-level Biology, it (Nuffield) was a self-teach method. I didn't like it, there was no help, just read; and no checking. It was laziness on my part. My results were poor — it had continuous assessment on practicals so I knew I was not doing well.'

Another was less critical:

'Of course (Nuffield Biology) was OK as a course — I know how to think of the subject and experiments and concepts. But I am lost on actual detail — the taxonomy of names. My contemporaries know, but I have only a rough idea, say "that's a leg"! It's good that it caused me to think, but should have got down to some rote-learning .... I had the time, but we weren't pushed to do it so I didn't: its my own fault. So I'm having to bone-up on information now as I need it. It's easier for me to think through experiments now — that's all the Nuffield course does, experiment after experiment to think through possibilities and what could go wrong. The Nuffield exam was more detailed — short answers. I find essays rather artificial after the other system — it changes the subject more into an Arts, not a Science, having to write long, boring essays.'

The Nuffield Physics student said:

'It requires a lot of self-motivation and self-study. Nuffield helps you develop yourself — the only books you get are the question books and you work through them at home.'

(3) Students' perception of common misunderstandings

Towards the end of the interviews I asked these students if they were aware of the frequency of misunderstandings, held even by their peers.
All these students were aware of great misunderstanding of the process of evolution by most people. In some cases this amounted to complete rejection. One student, a trainee teacher, said he would rather explain the concept to children than to his mother:

'She doesn't want to understand it. So even if children and adults have closed minds, they're (children) easier to open! My mother will change the subject or something.'

Another described an incident at school:

'It's even more than just Lamarckian — they actually don't believe in evolution at all. We had a matron at school who said: "You don't believe we are descended from apes do you?" It was a religious thing.'

The most thoughtful answer came from a student who had tried to explain it to a friend:

'...Another term for "survival of the fittest" in the modern world may be "the rat race". Most people, especially recently, are very concerned about the environment, and phrases like "the balance of nature" are quite fashionable these days ... the effects of pollution, radio-active waste, modern agricultural methods and land use, visual and audio pollution, and over-population. But I think very few people have any knowledge of the actual method by which evolution has taken place, or the mechanisms involved. From this they cannot realise that, because it has taken such a long time to progress, man is changing — more consistently and drastically — the environment, faster than natural processes can cope with "offering" new possibilities. They realise animals are becoming extinct and know that natural reserves are necessary for preserving wild-life because of man's intervention, but not exactly how man is influencing the evolutionary process. This may even apply to keen "amateurs" (e.g. naturalists, farmers), they may have no knowledge of the selective process. My friend was a bit sceptical about the idea of being able to attribute evolution to random mutation: that it seemed rather a spurious argument used to "gloss over" a fact that no more concrete explanations could be presented. Also that many parallels of modern day examples to primitive ancestors was speculating, and much "evidence" was used to fit the theory, rather than the other way round. Although he accepted the idea of the struggle for existence and "survival of the fittest!"

A major difficulty is for people to extend from natural selection to include the concept of time, which is intrinsic to the wider concept of evolution.
3.6 INDIVIDUAL LEARNING STYLES SHOWN IN INTERVIEWS

Educational research is actively exploring the way students learn. Pask and Scott (1972) identified 2 basic learning styles:

1. **serialists**, or step-by-step learners (subsequently generalised into 'operation' learners),

2. **holists**, or global learners (expanded to 'comprehension' learners).

These may be further categorised as 'redundant holists', describing those who introduce extraneous ideas and links, which are nevertheless vital components in the students' pattern of understanding. (see 1.4, Pask p.36)

Firstly, how many styles were used by these 9 students? Section 3.5 has described a remarkably consistent method of how these students would explain this concept, namely by the use of examples. However, on further analysis, it was apparent that the use of examples had been developed in quite different ways.

1. **The serialist.** Three students stated their explanation in a series of logical, clearly identified steps (often numbered), in building up the concept.

   'The best way is to use a specific, well publicized example, say DDT. Then to relate the theory to the example, first I would emphasize variation — there is a normal distribution of characteristics. Second, when the environment changes, this affects some in the spread, not others. Third, so only some left to breed.'

2. **The holist.** Three students linked natural selection, evolution and genetics throughout their explanations. In the most striking illustration, one student fell silent for nearly a minute after I asked him how he would go about explaining the concept to someone who knew nothing about it. He was obviously deep in thought. Finally, he said:

   'It's the start which is terrible. After you've started it's O.K.....' Another long pause followed, then he tried again:

   'It's very awkward, it may not be English.' With one breath, he then launched into the following account:

   'I'd start by saying that for the 2nd generation to a pair you've got to have as many as the 1st generation still alive to produce the 2nd generation, and if anything happens to the 1st generation so they can't reproduce, i.e. if they die or are infertile, therefore no 2nd generation will be produced by them. The 2nd generation would have the same characteristics
as the 1st generation had. So if there was a disease that killed off the 1st generation, those members of the 2nd generation which survived would have the immunity given to them by their parents, and there wouldn't be any non-immune members of the 2nd generation, because, (here comes the awkward bit,' he apologised with a quick breath),'the parents they would have had, if they were alive, would have died. That's it very very simply (!) and basically, as the process goes on, each generation becomes more and more selected against the disease, as time goes on.'

Later in this interview I asked this student about his own teaching experience. His answer suggested he could be classified as a redundant holist in this task:

'We never had to write an essay on it — oh, yes we did, on fruit flies; you know, those ones with shrivelled wings,' (he paused, struggling for the right word: I suggested: vestigial?) 'Yes, that's it! That was the example we used, for mutations. It is the only example that I can recall, so it must be a good one. I think I remember it because I thought shrivelled wings, (what's the word again?) were funny at the time, but I don't know why.'

3. A mixture of styles. Three students' explanations contained a mixture of these two styles. The following extract demonstrates an initial serialist explanation, which suddenly switched to a holist style.

A series of dots indicates where an example was mentioned.

'I would explain how genetic mutation gives different possibilities..., and how one possibility may thrive in a given set of environmental conditions. As further mutations occur, better advantages may arise ..., and those which become better adapted become predominant... If circumstances change however..., a trait that was before disadvantageous becomes advantageous...., this is because all organisms are in completion..., thus there is a struggle for existence..., this is how evolution has occurred....'

Suddenly this logical sequence was discarded; and he rapidly linked genetics, time, the environment and adaptation, without further examples:

'It is important to impress that mutations are random, chance occurrences. Time is required for evolution to occur. The environment is constantly undergoing change. An organism is adapted to its surroundings because, by chance, it has the advantage over other organisms for a particular set of environmental conditions at a particular time and place.'

4. Mismatch of teaching and learning styles

The two important questions asked in these interviews, i.e. (1) 'how was this concept taught to you?' and (2) 'how would you explain it?',
were designed to reveal if these students merely were repeating their own experience, or whether they did indeed have a personal style. The two students who most vividly described their original teacher's enthusiasm did basically repeat their own experience, on the grounds that 'it worked for me.' The following extracts demonstrate a problem two other students each experienced. I have interpreted their comments as a mismatch between teaching and learning styles.

(1) One of the students, whose explanation to Q2 identified him as a serialist, described a problem he had experienced:

'My teacher tried to give it in general terms, rather than taking a specific example as I have done with the giraffes. This made it slightly more vague, and therefore a bit more difficult to understand. However, when I read the example of the giraffes in Roberts (main textbook), I decided this was a very good way of actually remembering the principles involved, so I committed it to memory.'

His description suggests holist teaching, which he later sorted out to suit his own style.

(2) The second instance occurred during the interview of a student who showed a combination of styles during her explanation. She had explained:

'I'd take each piece of evidence and show how scientists believe it works'.

She then gave this evidence in an orderly step-wise manner, but for each step stopped and related many concepts to it, in a holist way. Later in our discussion she described a difficulty she was experiencing in her primary school teaching practice (her course was a combined B.Sc + Ed.):

'I'm finding it frustrating to make it simple enough for the 3-9 year olds. I can't get it down to the single steps they need to get through to progress up. I can see how I've done it, but I have to get it down to steps for them.'

She seemed to be struggling to develop a purely serialist teaching strategy, inconsistent with her own personal style.
DISCUSSION

These case-studies demonstrated the complexity of learning styles. Only one concept was involved in this study. Students did not all fall into either the holist or serialist categories, some showed features of both styles, supporting Laurillard's findings (1978). From a single set of observations, it was not possible to determine whether these styles were a characteristic of these students. There was some suggestion that students' learning style for this concept remained stable over several years. Those who were taught in a mis-matched manner later modified their learning to follow an individually preferred style.

The diagram in Appendix II is a 'concept map' of evolution (after Ausubel 1968). From this it may be seen that serialist students moved primarily vertically through the map, whilst holist students generally moved laterally in describing their concept understanding. Both methods resulted in sound understanding for the concept.

These preliminary observations on individual learning styles for biological concepts were intriguing. There were many unanswered questions, outlined in 1.4.

In extending this research to the main study I decided to include observations of learning styles. This resulted in the formulation of further research questions, recorded in 2.4. Interview data, used by several educationalists studying learning styles described in 1.4, had proved a satisfactory method of data collection in these pilot studies.

These pilot studies had thus been successful in testing aspects of the design of the main study. Several written problems had been shown to give reliable, valid observations of students' understanding of the basic biological concept, natural selection. Various techniques of observations (written open-response, multiple-choice questions, interview) and methods of analysis had been tested.

From the pilot studies two major conceptual themes arose for the main study:
1. to further explore the deeper understanding of the concept of evolution by natural selection, by including a study of related subordinate concepts,

2. to investigate students' learning styles- to determine whether they are a stable, mutually-exclusive characteristic of a student, or whether they are relative to a particular task.

A problem-solving approach provided data for analysis for both these themes. Both written tests and concurrent individual task-interviews were a valid method of observation and data collection for the main study.

3.7 SUMMARY

Validity of Assessment Questions (3.2)

1. MC/OR order did not affect students' performance if their understanding was sound; but this order did 'cue' students with incomplete understanding, restricting the range of their explanations.

2. Both OR and MCQ methods were reliable and valid for detecting the top students; and may be of use in assessing achievement. MCQ spread other students randomly and was very limited in diagnostic or evaluative assessment. OR ranked students well on their depth of understanding, and placed all non-Biology students in the lowest group. Choice of assessment procedures should take into consideration the objectives of the assessment.

Level of Concept Understanding (3.3)

3. Of 63 tertiary students tested, 14% showed sound concept understanding, and 65% showed very poor concept understanding. Of the 49 A-level Biology students, 18% showed sound understanding, and 59% poor understanding.

4. The occurrence of inconsistent or novel explanations between the two sections of the test suggested that some students may not be conserving this formal concept.
Origin of Misunderstandings (3.4)

5. A common map of misunderstanding was drawn, which showed where errors arose.


7. In addition to the majority of tertiary students who do not understand the concept of evolution, many also have poor understanding of the origin of mutations, laws of inheritance, immunity and modern medicine (the role of antibiotics), time and time-scales.

Interviews (3.5)

8. Individual, open-ended interviews with the 9 students with sound understanding of evolution by natural selection demonstrated the great value in the use of examples in teaching concepts.

Learning styles (3.6)

9. Analysis of interview data in terms of learning styles used for this concept showed 3 students used serialist style, 3 holist style, and 3 used a mixture of both these styles.
CHAPTER 4.

THE OKLAHOMA DINOSAUR PROBLEM

4.1 DEVELOPMENT OF THE PROBLEM

'About two million years ago dinosaurs roamed the earth. Many dinosaurs lived in Oklahoma. Dinosaurs were huge creatures. Some of them reached lengths of over 100 feet. All dinosaurs lived in water part of the time and on land part of the time. Most dinosaurs were plant eaters and they ate large amounts of plants of all types and sizes. The plants they lived on were found in water and around water.

Using the above information, write a paragraph which explains why you think dinosaurs are no longer found in Oklahoma.'

This question was originally designed by Professor John Renner of the Centre of Science Education, University of Oklahoma, for use in his CONCEPTS ANALYSIS PROJECT (Renner 1977).

The aim of this project was to develop written test material which could be used by teachers to evaluate students' level of intellectual development. In initial tests, students' intellectual level estimated by their written responses to several questions, (including the dinosaur question), was correlated with their concurrent performance in classical Piagetian task interviews.

The 'dinosaur' answers proved too complex to determine Piagetian levels, for many students did not use the information provided, but instead introduced various misconceptions they had about the causes of the extinction of species.

* The 'two million years ago' phrase should have read 'two hundred million years ago'. However after reading the replies of the students both Prof. Renner and myself are of the opinion that this omission did not influence the results. The students' responses suggested that the specific time given in the question was interpreted, at best, as 'a long time ago'. Some did not interpret the time given as even a long time ago since they referred to modern artifacts in their responses.
The concept of extinction may be described as a negative example of the concept of evolution, i.e. why a species does NOT survive. Therefore the content of these explanations was of interest to me, as part of my study of students' understanding of basic biological concepts, including evolution. During informal discussions in November 1977, Prof. Renner offered the 'dinosaur question' data for analysis.

4.2 ANALYSIS OF THE PROBLEM

The problem was originally designed to test students' level of formal reasoning. How suitable was it as a problem designed to test students' understanding of the concept of extinction (or 'why a species does not survive')? The information provided in the problem clearly mentions the following key points:

1. diversity in the dinosaur population
   ('Some were 100 ft' 'most plant-eaters')
2. variety of habitats ('in water and on land')
3. diversity of the plant population ('all types and sizes')
4. variety of plant habitats ('in and around water')
5. very large time-scale ('2 million years ago')
6. dinosaurs have not survived ('no longer found')

But one key point is missing, namely,

7. there was a change in the environment.

As a result of this change, no dinosaurs were suited to this new environment, therefore they did not survive.

The problem therefore tests for students' understanding of this missing key step which starts the chain of events leading to extinction (or evolution).
The information about plants and diets is, in fact, redundant to this explanation. By its inclusion, however, the vital step which results from the environmental change, i.e. 'only the fittest survive', is actually reinforced, for it can be applied to both dinosaur and plant populations.

4.3 Method of Data Collection and Analysis

Each problem was printed on a separate page, leaving approximately 2/3 page for the student's response. The dinosaur problem was one of a set of three, given to these students by Professor Renner.

The method of analysis has been described in 2.8. I wish to emphasize that the categories into which students' answers were placed, were developed after inspecting their protocols for common points. They were not my pre-determined categories. Where more than one reason was given, the main reason was used to calculate the percentage of students in the various categories, and the minor reasons were excluded.

4.4 Results

A total of 88 students attempted an explanation. The overall results are summarized in Table 1. These explanations are grouped into the categories of (A) sound understanding, (B) partial understanding, and (C) specific misunderstandings. This section also includes an analysis of the relationship between the factors of time and environmental change. The examples included as illustrations are the complete answers given by the students (in the examples, D = Dinosaur). The percentage given in each subcategory represents the percentage of the total sample who responded in this way.
Table I. DISTRIBUTION OF STUDENTS' EXPLANATIONS OF THE
DINOSAUR QUESTION INTO LEVELS OF UNDERSTANDING.
(Figures in each sub-category are the percentage
of the total sample who responded in this way.)

<table>
<thead>
<tr>
<th>Level of Understanding</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub-group</td>
</tr>
<tr>
<td></td>
<td>(A)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>(A) Sound Understanding</td>
<td>6%</td>
</tr>
<tr>
<td>(B) Partial Understanding</td>
<td></td>
</tr>
<tr>
<td>(i) Reason related to food</td>
<td></td>
</tr>
<tr>
<td>(a) Food gone ... dinosaurs died</td>
<td>10</td>
</tr>
<tr>
<td>(b) Competition</td>
<td>5</td>
</tr>
<tr>
<td>(c) No food, moved elsewhere</td>
<td>9</td>
</tr>
<tr>
<td>(d) Food 'now' insufficient</td>
<td>19</td>
</tr>
<tr>
<td>(e) Food eaten up</td>
<td>7</td>
</tr>
<tr>
<td>(ii) Reason related to time</td>
<td></td>
</tr>
<tr>
<td>(a) Eras of earth</td>
<td>5</td>
</tr>
<tr>
<td>(b) Extinction 'Q.E.D.'</td>
<td>11</td>
</tr>
<tr>
<td>(C) Specific misunderstandings</td>
<td></td>
</tr>
<tr>
<td>(i) Adaptation</td>
<td>3</td>
</tr>
<tr>
<td>(ii) Reproduction</td>
<td>6</td>
</tr>
<tr>
<td>(iii) Man</td>
<td>19</td>
</tr>
</tbody>
</table>

100%

(A) Sound Understanding (6%)

This small group of students gave a logical account of the sequence of events described in the question, which could have resulted in extinction. They all specifically recognized the unstated key step, namely that the environment had changed, which set off the chain of events leading to extinction.

'Many years ago the earth was mostly water. Through the years the land rose, the water disappeared and became confined to what are now oceans, seas and lakes. The dinosaur food supply, plants, was dependent on water. As the water vanished, so did the food supply. D needed large and many plants, when plants were no longer available D began to die and gradually became extinct.'
Shorter answers also contained all key points:

'Water in Oklahoma at that time was swamp and marshes and oceans reached into parts of Oklahoma. Then the climate changed to more arid, marshes dried up, sea receded. With the water gone plants died, and with this D passed away too.'

(B) Partial Understanding (66%)

In contrast to the foregoing group, the majority of students' answers ranged from moderate to extremely poor understanding. Answers fell into two main categories:

(i) Those which accounted for the absence of dinosaurs in terms of 'food', and
(ii) Those which used 'time' as their main concept.

Further sub-groups of these two main groups are described below.

(i) Food. Inadequate food needs was given as the prime reason for extinction by one half of all students. Six types of answers were identified, recorded from best to least partial understanding.

(a) 'Plants/water disappeared, therefore plant-eaters died'(10%)

This group consistently indicated a sequence of events, associating at least some of the information contained in the question.

'No more D in Oklahoma because there are no longer enough large bodies of water for them to live in, nor for plants that grew around water. With the disappearance of the water the dinosaurs also went.'

(b) Competition (5%)

A few students totally accounted for the dinosaurs' disappearance in terms of competition for food, either becoming victims of each other, or of other species.

'D were big and bulky and could not get away from smaller meat eaters.'

(c) 'No food left therefore had to move elsewhere'(9%)

Several answers left the reader wondering if one day he may come across nomadic dinosaurs migrating to 'seaside resorts'.

'If D needed water and plant life around water it is likely they'd go to places that had more water like Florida or the Great Lakes, or down by the coast.'
This group implicitly related the poor food requirements to today's environment, but with no clear description of a change in the environment, then or now. (An additional 14% mentioned this as a secondary reason).

'Because we do not have enough large water deposits. We also do not have enough plant life, vegetation, to feed D. Oklahoma is a state with lots of plains and is very dry sometimes.'

(e) 'Food eaten up'(7%)

This group showed the poorest understanding of the information given in the question. Food was seen as a non-renewable resource.

'No longer D found in Oklahoma because there were so many of them, they ate all of the food and in turn starved to death.'

(ii) Time as the main concept, was used by 16% of students.

(a) 'Era's of earth'(5%)

Five students mentioned the ice-age as either a complete or minor reason.

'One reason is because they all died during the ice-age over 2 million years ago.'

Nature acquired a 'planned obsolescence' role in evolution:

'One reason why D no longer roam in Oklahoma is that they were evolutionally disposed of, what you call one of the stepping stones of life on earth. When they became obsolete and were needed no more, they were naturally disposed of through nature to make room for another era in earth's history.'

(b) 'Extinction Q.E.D.'(11%)

Students using this explanation were considered to show the lowest level of understanding:

'Because two million years ago they all died.'

(C) Specific Misunderstandings (28%)

Many answers showed various types of misunderstandings, rather than the partial understanding described earlier.
(i) Adaptation (3%)

The dinosaurs' disappearance was attributed to their failure 'to adapt to' a changed environment.

'D are not found in Oklahoma because they could not adapt to the climate when the ice-age came in, so froze to death.'

(ii) Reproduction (6%)

Several students were unable to distinguish between reproduction of the individual and reproduction of the species.

'D are no longer found in Oklahoma because different types of animals do die off when there are no more born and eventually the ones that are here do die off. There is not that much water in Oklahoma anyway.'

Ignorance of the origin of a new species caused one student to suggest:

'Because they mated with other small animals they became extinct. They just didn't mate with each other. Another thing that could have happened is that D mated and changed considerably over the years and became smaller and we might know them as a different animal instead of a dinosaur.'

(iii) Man (19%)

One fifth of all students implicated man both directly and indirectly in the dinosaurs' extinction. Directly man either killed them, or destroyed their food:

'Because they were killed off faster than they were born. People were afraid of them so they were always trying to kill them all, and later on they did.'

'Because with all the tourists in the Grand Lake there are many boats and they tore up all the plants. Then they moved on.'

Indirectly, through space, water pollution, and problems caused by modern agriculture; modern man was also implicated:

'Man moved in and did away with a lot of plants to make room for his own wants - houses, big buildings, so there was not enough room for them (dinosaur) any more. So much of the water is polluted too.'

Overall, man's supremacy over other forms of life was summed up by the one student who mentioned 'evolution'.
'Time has had a great effect on the decline of the D. Evolution and civilization brought many changes to this world and its inhabitants. The size of D made it impossible to live wild in the day and time. Much of Oklahoma's water is used for specific purposes. Water plants are scarce in these waters. D could not compete with man's advancement.'

Analysis of the Relationship Between Time and Environmental Change

In the light of the disturbing results found in this study, all students' responses were re-examined to identify those who had made a specific mention of a 'change in the environment' (either climatic or geographical), to see how far they had related this change to the concept of 'time'. Overall 20% of students had attempted this. They fell into 3 clear groups:

(i) The sound understanding group (6%) described in Results Group (A).

(ii) The ice-age group (5%) described in Group(B)(ii), plus one student categorized (C) (i) adaptation.

(iii) Vague mention (9%)

'Earth was swampy back then, their way of living, and when the earth changed, they died.'

4.5 DISCUSSION

At the outset it should be clearly stated that I assumed these responses genuinely reflected students' understanding, and were not written in jest. The question was answered as part of a set, the other questions providing reliable measures of students' intellectual achievement. The topic was selected on the grounds of familiarity to students at this level of education. Any syllabus on 'the fossil record', or 'the age of dinosaurs', should include the time-scale of the evolutionary history of life on earth.

Poor understanding of this concept of time, and a time-scale of huge dimensions, seems to be the basis of all the misconceptions shown in the results. This is highlighted by the finding that 20% of these
17-year old Oklahoma students implicated Man in causing the extinction of dinosaurs! Are these students simply ignorant of when the first man-like animals appeared on earth? Taking the results overall, I believe such an explanation is too simple. Students have consistently interpreted events of the past in terms of problems of the present, a time-dependent 'anthropocentric' view. Contemporary issues such as the conservation of resources ('food used up', 'dust-bowl'); pollution, ('poisons', 'chemicals', 'water pollution'); and the threatened extinction of many species today, all describe the effect of modern, technological man on the natural environment today. Many students do not seem to be able to visualize any other world but their own.

Only 6% of these students demonstrated logical reasoning of the process of extinction. In Chapter 3, pilot studies of 63 British 18-year old students showed only 18% understood the concept of Darwinian evolution after A-level Biology studies, and correctly applied it to unfamiliar environmental problems. These disturbing results from two countries suggest that this concept has not been grasped by the majority of Biology students by the time they leave secondary school, and that teaching methods for this concept should be critically revised.

4.6 SUMMARY
1. Written answers to a problem on the extinction of dinosaurs in America, given to 88, seventeen-year old American High school students, revealed that only 6% of these students were able to correctly identify extinction as a (negative) example of natural selection.
2. Two-thirds (66%) of students showed partial understanding of the process of evolution by natural selection.
3. Three kinds of misunderstandings, (i) adaptation, (ii) reproduction errors and (iii) man, accounted for the remaining 28% of answers to this problem.
STAGE 2. MAIN STUDY

STUDENTS' PERCEPTIONS OF BIOLOGICAL CONCEPTS
CHAPTER 5.

UNDERSTANDING THE CONCEPT OF EVOLUTION BY NATURAL SELECTION

In the 1976 Victorian HSC Biology exam, the major compulsory essay was set as a problem requiring the application of natural selection in the mechanism of evolution. Essays from over 10,000 students showed that the majority of Victorian Biology students had extremely poor understanding of this concept. (Appendix I)

The pilot studies (Stage 1) of post A-level British Biology students at entry to tertiary studies showed a similar disturbing picture - only 18% being able to consistently identify and apply this concept to unfamiliar problems, (Chap. 3, and Brumby M. 1979).

This chapter describes the extension of these observations in the main stage (Stage 2) of my project.

5.1 ANALYSIS OF THE PROBLEMS

As has previously been described (2.5), a set of 5 problems using this concept was given to students in one of two ways, three were in a written test which replaced a normal course lecture in the second week of the first term, the remaining two were given during individual task interviews. Unlike the open-ended problems exploring students' understanding of 'life' (Chap. 6), these problems had definite correct and incorrect explanations.

A. WRITTEN TEST

A.1 The Insecticide Problem.

'When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed. Why do you think this is so?'

This problem had been used in the pilot stage 1 and had proved a reliable, valid question. In the written test it was given in both
the open-response (OR) format (A.1), and also as a multiple choice question (MCQ), shown below as A.7. Six questions separated these two versions. The inclusion of the MCQ was primarily to illustrate this form of objective questioning, in order to ask students of their experience with such questions. It also tested their concept understanding (in Stage 1, level of difficulty $P=0.49$)

A.7

'When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed.

The reason why fewer insects are being killed is that:

A. Mosquitoes which survive spraying develop an immunity to the insecticide.

* B. Many mosquitoes today are descendants of mosquitoes with insecticide-resistant characteristics.

C. Mosquitoes are adapting themselves to this man-made change in the environment.

D. The original spraying has caused a permanent mutation giving genetic resistance to the spray.'

In this problem both the change in the environment, (the introduction of insecticide,) and the target population (insects) are identified. Correct reasoning is that in a changed environment, only some individuals have characteristics enabling them to survive, the others will not survive (or are selected against). Therefore those organisms with such a suitable genetic characteristic, (which has arisen by spontaneous random mutation) will have a survival advantage, reproducing offspring also possessing this characteristic and hence, over generations the population as a whole becomes proportionally better adapted to its environment. Since the generation time of insects is much shorter than man's, many insect generations will occur in the 20 year time span given in the question.

* correct answer
A.2 The Dinosaur Problem.

'About two hundred million years ago, dinosaurs roamed the earth. They were huge creatures, some reaching lengths of over 100 feet. All dinosaurs lived in water part of the time and on land part of the time. Most dinosaurs were plant eaters and they ate large amounts of plants of all types and sizes. The plants they lived on were found in and around water.

Write a short paragraph which explains why you think dinosaurs are no longer found.'

This problem was modified from Prof. J. Renner's 'Oklahoma Dinosaur Question', (chapter 4, and Renner J and Brumby M 1979, paper submitted for publication in The American Biology Teacher).

Results obtained from 88 17-year old American High School students had shown that very few students saw the extinction of dinosaurs as a problem of evolution.

The problem of extinction is an example of 'negative' selection, i.e. why a species does NOT survive. The essential (missing) step to be identified by students is that there must have been a change in the dinosaurs' environment. Following this change, the variation in the dinosaurs' populations did not contain any individuals with characteristics enabling them to survive, ... they died out. Both points (the change in the environment and the selective process), had to be made in a complete answer to this question.

A.4 The Antibiotics Problem.

'Scientists have warned doctors against the increasing use of antibiotics (e.g. Penicillin) for treating minor infections.

What is the reason for their concern?'
This problem had been used in the pilot Stage 1 and had proved valid and reliable. However during 1978 scientific observation of bacterial resistance being transmitted via the plasmids occurred, i.e. a kind of genetic 'infection'. This throws doubt on selection being the sole mechanism altering the frequency of resistance in bacterial gene pools.

The problem was originally designed as an extension of the insecticide problem, for again the change in the environment, (addition of antibiotic), is identified, but now there are two populations present - bacterial and human, and students have to identify the target population. Since this problem had revealed serious misunderstandings in the pilot study, I decided to re-use it in the main study (in its open-response written form only).

Any student who answered in terms of resistance 'infection' would immediately be detected. A process of 'infection' does not remove the problem of distinguishing between a process of selection and a process of adaptation, which was a primary focus of these studies. (Note that in the written test, the insecticide and antibiotic problems were not consecutive).

B. TASK INTERVIEW

B.2 Concepts Identification Question.

'What are the basic concepts or ideas that are contained in these questions?'

This question had been used in the pilot study and confirmed that only those students who explained the problems in terms of natural selection, could identify this concept (or evolution). Poor students identified 'immunity' or 'the effect of chemicals and drugs' as the concepts contained in the problems.

In the main stage I asked this question orally, towards the
beginning of the interview. Before asking the question I put each student's written answers to the insecticide and antibiotics problems in front of him. Students were given time to re-read their answers if they wished.

B.4 The Skin Problem.

I placed this large (60 cm x 40 cm) patchwork picture of human skin colour variation in front of each student and asked:

'If we suppose that man originally arose in one place, say in Africa, where some of the oldest human skulls have been found, then how do you account for the different skin colours that exist in the different races round the world today?'

After students had given their explanation I asked two further questions:

(a) 'What would you predict to happen to this couple's skin (dark-skinned), if they went and lived permanently in Norway?'

(Answer)

'If they had children born in Norway, what would their children's skin look like?'
(Answer)

(b) 'What would you predict to happen to the skin of this little girl, (very light-skinned) if she went and lived in Africa for the rest of her life?'

(Answer)

'If she married someone of her own race, they lived in Africa, and had children there. What would their children look like, at birth?'

In the first part of the skin problem there were several points required in a full explanation. Firstly, students needed to mention that pigment production was genetically mediated. Secondly, the presence of pigment gives a selective advantage in tropical countries, due to its U/V screening property. Further, the problem had postulated that man had originated in Africa, i.e. a hot climate. Therefore man may have been dark initially. In moving to cooler climates, students had to explain that there must be a selective advantage in having a lighter skin, i.e. one with less melanin pigment. They were not required to state what this advantage was, but biologically sound reasons such as 'the increased production of Vitamin D in the skin', or 'increased heat absorption without the danger of U/V radiation' confirmed such students' sound understanding of natural selection.

This question aimed to clearly identify students who wrongly explained in terms of a process of adaptation, based on the 'needs' of people in different climates. Such reasoning is the Lamarckian theory of evolution, and can be applied to both skin becoming dark, (or remaining dark), and to skin becoming lighter, by 'losing' pigment.

There is a subtle difference between these two changes (i.e. becoming dark or light). 'Becoming darker-skinned', i.e. gaining pigment, occurs naturally within a lifetime - i.e. in suntanning. This is a familiar experience. However 'becoming lighter-skinned',
i.e. losing pigment, is not familiar within a single lifetime. This difference tests for the appreciation of a time-scale of many generations in evolutionary change.

The subsidiary questions on Norway and Africa were designed to test students' grasp of genetics, and the distinction between acquired characteristics (phenotypic), which are the appearance of an individual in a particular environment, and which are NOT passed on, and genetic characteristics (genotypic), which ARE inherited. It also tested further the idea of many generations required to change the frequency of alleles in the human gene pool.

5.2 DATA COLLECTION AND ANALYSIS

The student population participating in the Main Study has been described in 2.7. The use of two methods of data collection, (a) written and (b) by interview, and the development of the problems is contained in 2.5. The complete written test and task interview schedule are included as appendices IV and V respectively.

All students tackled all problems. They were particularly enthusiastic about the task interview problems. The 'skin' problem (B.4) followed the 'Rock' problem (see Chap. 6), which had intrigued students, and they turned to the skin picture with considerable interest. Utmost care was taken to ensure that, in the interviews, questions were identically worded for each student.

In analysing their explanations, I followed the basic method described in 2.8. I wish to emphasize that categories were developed by reading their protocols and finding common points, they were not my pre-determined categories. Thus the table of results was developed at the end of my analysis. Its inclusion at the beginning of the Results section, 5.3 is for clarity only.
5.3 RESULTS OF INDIVIDUAL PROBLEMS

The results of the four problems are presented in tabular form. Examples of each category follow. These separate results are then combined to determine, for each student, their overall understanding of the concept of evolution by natural selection (5.4).

The fifth question, concepts identification, is described separately (5.5) and used to confirm the overall results.

Misunderstandings which were observed are then discussed in detail (5.6).

<table>
<thead>
<tr>
<th>Table I.</th>
<th>ANALYSIS OF NATURAL SELECTION PROBLEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HB</td>
</tr>
<tr>
<td>A.1 Insecticides</td>
<td></td>
</tr>
<tr>
<td>MCQ. Right</td>
<td>20</td>
</tr>
<tr>
<td>Wrong</td>
<td>12</td>
</tr>
<tr>
<td>OR. Right</td>
<td>8</td>
</tr>
<tr>
<td>Wrong</td>
<td>24</td>
</tr>
<tr>
<td>A.2 Dinosaurs</td>
<td></td>
</tr>
<tr>
<td>Change in env/selected</td>
<td>6</td>
</tr>
<tr>
<td>Change in env.</td>
<td>15</td>
</tr>
<tr>
<td>Selection</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
</tr>
<tr>
<td>A.4 Antibiotics</td>
<td></td>
</tr>
<tr>
<td>Bact. selected</td>
<td>2</td>
</tr>
<tr>
<td>Bacteria target</td>
<td>16</td>
</tr>
<tr>
<td>Wrong</td>
<td>14</td>
</tr>
<tr>
<td>B.4 Skin</td>
<td></td>
</tr>
<tr>
<td>Selection</td>
<td>5</td>
</tr>
<tr>
<td>Wrong</td>
<td>27</td>
</tr>
<tr>
<td>Norway: children born lighter</td>
<td>-</td>
</tr>
<tr>
<td>Africa: children born darker</td>
<td>4</td>
</tr>
<tr>
<td>No. of students</td>
<td>32</td>
</tr>
</tbody>
</table>
As there was no significant difference between the two groups of students, the following comments apply to the Total column.

A.1

The insecticide question gained the largest number of correct explanations. In the written, OR format 25% of all students correctly explained in terms of selection. (The MCQ question gave a considerably larger number of correct answers, P=0.6, and was not considered in the final analysis).

'Through a process of natural selection. The immune insects proliferate because their genetic make-up differs from that of their dead contemporaries, either because of a mutant gene or because of a once recessive gene which confers immunity, becoming dominant.

Also because "all" insects which are affected die, this means that the genes conferring immunity become more prolific, i.e. their frequency increases. Therefore there's more chance of two immune insects mating and passing their immunity on to their progeny and so on through later generations, with the number of immune insects always increasing relative to the insects without the gene.' (No. 26)

75% of students either did not understand the problem or were unable to express themselves accurately. Of the mistakes made by these students, the concept of 'immunity' was the most frequently mentioned. (see Table III)

'The insects have gradually, over the years, obtained immunity to the insecticides. These immunity factors are passed on from generation to generation, gradually building up so immunity increases.' (No. 2)

A.2

In the dinosaur question, only 19% correctly completely explained both key points, that following an (unknown) change in the environment, no dinosaurs had any characteristics enabling their survival, so all were selected against by the environment and died out.
'They are no longer found because evolution has occurred. The plants that the dinosaurs ate would very likely have become scarce due to 'overgrazing' by the dinosaurs. The population pressures on the land increased and the animals that were able to live on different food and different living conditions would be selected for. They may have also died off as the earth became less wet and hence their habitat was removed.' (No. 18)

A further 42% identified the missing step, 'the climate changed', but either didn't explain the consequences or went on to explain, 'the dinosaurs couldn't adapt and so they died.'

Two students (4%) mentioned the phrase 'survival of the fittest', without mentioning any prior environmental change.

The most common other reason was 'competition with other animals.'

'Insufficient food', 'restricted movements on land', and the now familiar 'they couldn't adapt' accounted for the remaining 35% of students.

One student repeated the extraordinary anthropocentric view seen in 20% of American high school students (4.4):

'A.4

'Due to the population on earth increasing every day, there's no room to support these creatures - they would take up housing space and deprive the human race. Their size requires huge amounts of food, which would deprive man, so man has killed them.' (No. 45)

The antibiotics problem again showed serious misunderstanding of the action of antibiotics, as had been shown in the pilot studies.

Although 29 students (56%) identified bacteria as the target population, only 3 students correctly explained the selective action of the antibiotics:

'Bacteria, the organisms that are affected, have genetic variation, so some will not be harmed. On a small scale this is not significant, but if overused the unaffected will survive and give rise to the development of an immune strain, (as in V.D.) so more people are suffering.' (No. 49)

The other 26 students all believed: 'bacteria become immune.'

The remaining students (44%) incorrectly identified man as the target population:
'The body will become used to the antibiotics, ... may not react so strongly when treated, ... effectiveness will decrease.' (No. 8)

'The patient will develop an immunity to penicillin, and it may not work efficiently in a major illness' (No.13)

'If used in minor illnesses it will be of no use in serious illnesses, it will be useless and not work.' (No.42)

No student mentioned transmission of genetic resistance by 'infection' with plasmids.

B.4

The skin problem was presented orally. Only 8 students (15%) correctly explained the hypothesis in terms of natural selection, the presence of pigment being advantageous or disadvantageous in the tropical or cooler climate respectively.

'From what I've read, if man did evolve from Central Africa, then darker skin is likely first, and lighter skin evolved later. You're getting back to the mutation and presumably there's people in the north of the equator and there's some advantage in having a lighter skin than people living nearer the equator. A lighter skin is presumably mutations of the right gene, (I get a bit confused about this because from the physics I did I'd expect skin colour to be reversed, the lighter skin to reflect the U/V rays)... It must be environmental pressures - Darwin's survival of the fittest.' (No.9)

There were three common errors in answering this problem:

(i) the development of pigment is caused by U/V rays:

'Climate has a lot to play in that - the amount of exposure to the sun and the sun's radiation near the equator - you're relatively closer to the sun, ... the greater the chance of U/V rays getting through to the bone marrow. They're the ones that cause the tanning of the skin, ... the closer you are to them, the greater the chance of being tanned, ... you get colour variation.' (No. 19)

(ii) loss of pigment is because it was not needed:

'There isn't a need for the pigments or protection from the sun so much in countries further away from the equator. It wasn't necessary, because like in summer you get darker pigmentation than in winter, like coloured people in this country. (My friend is Asian and she goes darker in summer). With there not being so much use of this pigment, eventually it's not being built up in summer so much, so gradually it's not being used at all.' (No. 47)
(iii) by adaptation:

'It's adaptation to the power of the sun. There is a need for a filter in the skin to stop U/V rays penetrating. This need either increases or decreases, depending on the environment.' (No. 4)

N.B. Many students did not appreciate the significance of the common origin being Africa, and accounted for variation in skin colour totally in terms of production of pigment, i.e. assuming the original skin colour was light.

These observations were not surprising, because of the poor understanding shown in the written problems.

The two further probing questions on Norway and Africa migration and children were designed to focus on the differences between changes occurring in one generation and changes occurring over many generations.

Migration of dark-skinned people to Norway troubled only two students, who thought the children born might be born slightly lighter-skinned. All other students were definite that they would stay the same (or any loss of pigment be unnoticeable), and that their children would also have the same dark skin.

The reverse migration, i.e. light-skinned people going to Africa and subsequently having children born in Africa proved more difficult. All students said that they would become suntanned or slightly darker, (but not black as Africans). Nine students (17%) predicted that their children would be slightly darker than they were - AT BIRTH i.e. in one generation.

5.4 OVERALL LEVEL OF UNDERSTANDING OF THIS CONCEPT

Table II shows the overall distribution of students, when their performance on all these problems was combined. Using an ordinal scale of measurement, allocating 1 mark to each sound explanation in each problem, and ½ mark in Q. A.4 the identification of the target bacterial
population, and A.2 the change in the dinosaur's environment, students were grouped into Good (4 or more), Moderate (2-3) and Poor (<1).  

Table II. OVERALL DISTRIBUTION OF STUDENTS INTO LEVELS OF UNDERSTANDING OF THE CONCEPT OF NATURAL SELECTION

<table>
<thead>
<tr>
<th>Level of understanding</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>15%</td>
</tr>
<tr>
<td>Moderate</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>17%</td>
</tr>
<tr>
<td>Poor</td>
<td>21</td>
<td>14</td>
<td>35</td>
<td>68%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100%</td>
</tr>
</tbody>
</table>

Only 8 students (15%) demonstrated good understanding of natural selection. 9 (17%) students showed moderate understanding. Over two-thirds of these 52 students (68%) were unable to recognize that these were problems of evolution by natural selection.

5.5 CONCEPTS IDENTIFICATION QUESTION

Students' answers to this oral question B.2 were analysed in two ways. The frequency of concepts was determined as shown in Table III, (a). They were then re-grouped according to the classification of students into levels of understanding, from Table II. This distribution of concepts is shown in Table III (b).
Table III. CONCEPTS IDENTIFIED DURING TASK INTERVIEWS

(a) Frequency of concepts

<table>
<thead>
<tr>
<th>Concepts</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection/evolution</td>
<td>6</td>
<td>7</td>
<td>13</td>
<td>25%</td>
</tr>
<tr>
<td>Gene mutations</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>9%</td>
</tr>
<tr>
<td>Resistance</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>17%</td>
</tr>
<tr>
<td>Adaptation</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>8%</td>
</tr>
<tr>
<td>Immunity</td>
<td>11</td>
<td>6</td>
<td>17</td>
<td>33%</td>
</tr>
<tr>
<td>Chemicals/drugs</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>32</strong></td>
<td><strong>20</strong></td>
<td><strong>52</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

(b) Distribution of concepts

<table>
<thead>
<tr>
<th>Concepts</th>
<th>GOOD</th>
<th>MODERATE</th>
<th>POOR</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection/evolution</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>13</td>
</tr>
<tr>
<td>Mutations/resistance</td>
<td>1</td>
<td>2</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>Immunity</td>
<td>-</td>
<td>1</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Adaptation</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Chemicals/drugs</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>8</strong></td>
<td><strong>9</strong></td>
<td><strong>35</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

Table III (a) showed that 6 concepts were identified. Most students gave only one. Where more than one was given, the first one was used in distributing students. By combining gene mutations and resistance, as in Table III (b), these multi-answers were virtually deleted.

Table III (b) clearly showed the significance of the selection/evolution concept identification, and confirmed the validity of the student's classification from this set of problems.

Table III (b) also showed that those students who listed 'adaptation', and 'mutations', (which theoretically could be relevant concepts) were not using these concepts correctly. The misunderstanding of the concept of immunity was almost totally restricted to the group with very poor understanding.
5.6 DISCUSSION

The overall distribution, shown in Table II, confirmed the pilot finding that about two-thirds of post A-level Biology students were unable to identify and apply the concept of natural selection to either familiar or unfamiliar problems.

Only 15% of these students showed a good understanding of the evolutionary process, and a further 17% showed some understanding, but could not explain the skin or the antibiotics problems.

The most important, consistent mistake which was observed was to interpret change on the basis of need. This is the Lamarckian theory of evolution.

The steps leading to misunderstanding have been described in the pilot study. They are equally applicable to these students. The following points should be highlighted.

1. The first and fundamental step, that populations contain individual variation, which arises from spontaneous mutation, is absent. Instead, students believe that mutations are caused by the environmental change for which it is specific.

2. Adaptation is described as a positive process, rather than the end result of selection of the better adapted. This problem of the poor definition of the concept of adaptation has been discussed by Lucas (1971), who criticized the looseness of language in both textbooks and examinations. Students confuse the passive verb 'to be adapted' as being synonymous with the (incorrect) active verb, 'to adapt'.

3. Students do not take into account the time-scales of evolution. They extrapolate from changes seen to occur within one lifetime, (e.g. suntanning, immunization), to account for apparently similar genetic changes seen over many generations. However such acquired
characteristics are NOT inherited by future generations, and immunity is NOT 'passed genetically on'. It was interesting to note that students found it easier to explain the acquisition of a characteristic on the basis of need, within one generation, than to explain the loss of an unwanted characteristic in the same time-span. This was shown most clearly in the 'Skin' problem, when dark-skinned people would have dark-skinned children in Norway. The loss of pigment of people in colder climates was usually said to take 'thousands of years'. However 17% of students could not reverse the argument and postulated that light-skinned people living in Africa would have slightly darker children, (i.e. first generation).

4. Students do not take numbers into account. Changes in an individual are not the same as changes in a population. Population changes are caused by changing the proportion of individuals in that population. Thus a population changes, not by individuals becoming more immune, but by more individuals with 'immunity', (through selective breeding).

5. Students misused the word 'immunity', usually as meaning 'genetic resistance'. This word is currently abused in everyday language and is in danger of losing its precise scientific definition. Even though 'Immunity' is not part of the A-level syllabus, these students chose it unhesitatingly. Similarly 'evolve' is synonymous in everyday language with 'develop'. In such a context 'evolve' loses its implicit 'selection' component.

6. This study focused on the concept of natural selection. The results suggested that other biological concepts - adaptation, immunity, heredity - may show similar poor understanding.
A series of recent articles has highlighted problems associated with the teaching of evolution in schools. Most authors have focused on the importance of Darwin's theory of evolution by natural selection.

Firstly, the emphasis given to this concept within the syllabus has been criticized. In the United States, publicity by the procreation movement has resulted in Government intervention into school curricula, textbook revision and the suggestion of equal time to the concepts of special creation and organic evolution, (Mariner 1978). In Britain, Harper's claim that the emphasis given to Darwin amounted to indoctrination, has been vigorously debated (Harper 1978).

Secondly, actual teaching practice has drawn comment. Angseesing (1978) has criticized loose terminology by teachers and the mass media. He believed many of these inaccurate phrases contribute to students developing a confused Lamarckian view of evolution, (i.e. change on the basis of need). This is in contrast to Dawes (1977) who recommended repeating some of Kammerer's original experiments which are difficult to explain in terms of Darwinian theory.

All of these articles are written from the teacher's point of view. Implicit in their discussions is the assumption that students 'learn' exactly what they are 'taught'.

From the students' point of view, other reports have indicated that students find evolution a difficult concept. Its place in the O-level Biology syllabus was questioned by Shayer (1974) in his evaluation of the revised O-level Nuffield Biology syllabus. After investigating the proportion of students at the Piagetian level of formal operations, (essential for understanding abstract concepts), Shayer suggested that the evolution-heredity section be omitted as being conceptually beyond the majority of students at O-level.

Curiosity is not confined to formal studies, and Piaget (1973) has extensively studied children's 'intuitive' ideas about the world.
Detailed observation on the preconceived understanding of evolution and heredity, held by a group of 11-14 year old boys, have recently been described by Deadman and Kelly (1978). They concluded that, before formal studies of these concepts, most boys had a naturalistic or Lamarckian interpretation of evolution.

At A-level, evolution and heredity are central concepts, included in the A-level Biology syllabus of all examining boards. Tertiary biological studies assume a sound understanding of the basic principles of Darwinian evolution. These observations, together with the pilot study (Chap. 3) reveal that the majority of these post A-level students undertaking tertiary biological studies, have not grasped the central concept of natural selection. Indirectly it has also revealed that other basic biological concepts, (adaptation, immunity and heredity) have also been poorly grasped by many students.

The pattern of misunderstanding was essentially similar to the Lamarckian interpretation of evolution, reported by Deadman and Kelly (1978). Even after completing A-level Biology, the majority of students tested still believed that organisms 'can gradually adapt to a change in the environment', if they 'need to', and hence 'evolve'. Together with Deadman's report, this finding suggests that pre-existing (Lamarckian) beliefs have acted as a barrier, which has blocked the formal learning of Darwin's theory.

In the light of these findings, Harper's accusation of 'Darwinian indoctrination' in the classroom is a theoretical, rather than a real problem.

In considering ways of improving the teaching of evolution, Dawes' suggestion of repeating 'Lamarckian-type' experiments runs the risk of reinforcing intuitive misunderstandings.

The wider issues of the 'evolution debate' have clouded the problems students have, in understanding the fundamental concept of natural
selection - Teachers need to 're-teach' this concept, in order to
overcome this pre-conceived misunderstanding which blocks the
understanding of the basic concepts determining the continued evolution
of life on earth.

5.7 SUMMARY

1. Five problems involving the application of the concept of
natural selection were given to 52 tertiary biology students,
in a written format and during individual task interviews.

2. Overall, 15% of students consistently identified and correctly
applied a process of selection to these problems.

3. Another 17% showed partial understanding.

4. Two-thirds (68%) of these students were unable to explain these
problems correctly.

5. Their interpretation was basically Lamarckian evolution - i.e.
change on the basis of need. In doing this, students failed to
appreciate the difference between changes acquired during the
lifetime of an individual, and changes in the proportions of
individuals with certain characteristics in populations,
occuring over many generations.

6. This resulted in their explanations describing a process of
adaptation instead of a process of selection.

7. These results also revealed misunderstandings of other basic
biological concepts.
CHAPTER 6.

TOWARDS A DEFINITION OF LIFE

Biology is the science of life. Life, therefore, may be considered the most fundamental of all biological concepts.

The concept map of evolution (Appendix II) shows that life is a subordinate concept to the concept of evolution by natural selection. It is closely linked to the concept of the biosphere, the life-supporting natural environment. Many studies of the concept of life have been analysed using Piaget's stages of animism, (Piaget 1973) and have been extensively reviewed by Looft and Bartz (1969). Most studies have focused on young children, and have used familiar objects. For example Smeets (1974) studied six characteristics (grow, feel, hear, know, talk, die) on such objects as cat, fish, tree, flower, cloud, river, clock, car. The use of familiar objects has been criticised by Looft (1974) as not exploring the child's complete understanding of this concept, and he recommended the use of an unfamiliar object in order to study the criteria used to determine whether the object is alive. There has never been a single definition of the concept of 'life'. The traditional 'seven characteristics of living organisms' were: 1) Growth, 2) Reproduction, 3) External Respiration, 4) Nutrition, 5) Excretion, 6) Irritability, 7) Locomotion.

The invention of the microscope resulted in the identification of a structural criterion to the older idea of constancy of composition of living organisms, i.e. the presence of 'cells' as the 'units' of life, with a boundary making the cell distinct from its environment.

Further scientific advances made possible the development of sophisticated biochemical techniques which resulted in more exact
characteristics of living organisms: the presence of
(a) organic constituents — DNA, functional protein, glucose,
and
(b) energy transformation, — cellular respiration.

The 'traditional seven' clearly favour the animal kingdom at
a complex, multi-cellular level. All characteristics listed above
can be combined to form an operational definition of the concept of
life, i.e. what can a living organism do in order to be considered
alive, rather than a nominal or objective definition such as 'what
is life'.

The chief questions forming the basis of the study of the concept
of life, held by these tertiary Biology students were:
1. How did Biology students characterise living organisms?
2. What criteria did they use to discriminate alive: dead: non-living?
3. Did their idea of 'life' include the essential interrelationship
   between an organism and the biosphere?

6.1 ANALYSIS OF THE PROBLEMS

In the written test, two problems related to the concept of life:
A.5 the Fire problem, and A.6 the Mars problem. In the task interviews,
two problems related to the concept of life: B.3 the Rock problem and
B.4 the Web problem.

These four problems were all open-ended, or divergent, in the
sense that there was no single correct answer, and there was more than
one satisfactory answer (Guilford 1967).

A. Written test problems.
A.5 Fire Problem

'To a small child, the flickering flames of a fire seem "alive".

(a) Why do you think a young child believes that fire is alive?
(b) What other characteristics of fire could be used to support this belief?
(c) Why do you believe that fire is not alive? (Assuming that you do!)

One third of an unlined page was allowed for each part of the question.

The primary aim of the question was to challenge the students' analytical skills in applying their understanding of characteristics associated with life. Fire is familiar, and known to be non-living, yet it shows many of the seven traditional characteristics. The more the students showed this to be so in A.5 (b), the more difficult it became to tackle A.5 (c), i.e. why do you believe fire is not alive? Insofar that A.5 (c) allows for novel, or original explanations, it may be revealing creative potential. (Guilford 1967).

A.6 Mars Problem

'If you were on the first manned spaceship to land on Mars, what evidence would you look for to determine whether living organisms existed there?'

Three-quarters of an unlined page was allowed for the answer.

This question included the possibility of a life-form which is grossly unfamiliar to any present on earth. Further, it tested students' awareness of the properties of the biosphere on which life is dependent.

B. Task interview problems.

Written answers involve pre-thought, and have a degree of structure and formal expression. Part of my interest in problem-solving was to observe the learning styles of these students. For this a 'spontaneous' approach was required, therefore two problems on life, included in the interview, required students to 'think aloud', as described in Chap. 2.5. All oral tasks contained visual material. The two 'life' problems came after the students had answered two short attitudinal questions, and were talking freely.
B.3 The Rock Problem

'If you were out in your vegetable garden and you came across this, how would you go about finding out if it is alive, if it was once alive but is now dead, or if it has ever been alive, i.e. is non-living?'

The picture showed a totally unfamiliar object; greyish-green and very difficult to tell its texture merely by inspection. Students were NOT allowed to touch it, (although 95% instinctively attempted to!) This question focused on experimental testing of the hypothesis 'if it is alive.....! (The object is, in fact, a water-weathered stone washed up on a beach).
B.5. The Web Problem

'You sometimes hear people using phrases like: "All of life depends on green plants", or they may speak of "a web of life". What do you think people actually mean when they use these phrases?'
'(here is a diagram of a cobweb if it helps you to explain by drawing on it)'

The primary aim of the double-barrelled question was to focus on the essential role of photosynthetic plants in converting solar energy and inorganic elements (nitrogen, carbon) of the biosphere, into a complex organic form utilizable by all other organisms. The production of oxygen, a by-product of photosynthesis is a secondary factor. Less than half the students marked the diagram, its main purpose consequently being visual material only.
6.2 RESULTS OF INDIVIDUAL PROBLEMS

Reasons given by students were identified and listed. The frequency of these reasons was then established. In the tables of results, the 32 Human Biology (HB) and 20 Nursing Studies (NS) students have been recorded separately. After all reasons had been listed they were grouped into biologically related categories, i.e. these categories, shown in the left-hand column were identified after students' explanations had been analysed and were not my pre-determined categories. Since students were able to give more than one reason, the figures are the absolute frequency of reasons. The right-hand column shows these as a percentage of each sub-section of the question. For any one reason, the figures also represent the number of students who mentioned that reason.

Table I shows that in their explanations to A.5 (a) a total of forty-eight out of the fifty-two students listed 'movement'. I did not categorize these further into the Piagetian stages of animism, (1. activity, 2. movement, 3. spontaneous movement). (Piaget 1973). Of these forty-eight, (18 HB + 10 NS = 28), 54% of all students gave this as the only reason, and went on to list the other 'descriptive' criteria in (b), as further reasons supporting the child's belief.

In A.5 (b) students gave varying comparisons of the characteristics of fire which were very similar to the traditional 'seven characteristics of life'. Nearly half of all reasons were applications of the 'seven', often in some detail: fire 'grows' 'moves', 'eats' organic material as it burns, 'breathes' (needs oxygen to stay alive), 'excretes' waste products (smoke, ash, smells).

Eight students made a further detailed comparative analysis of respiration, 'it may even be said to show metabolic processes, in that it uses oxygen to oxidize organic fuel, releasing free energy' (No. 20). These eight students are recorded in Chapter 8 as showing a highly analytical style for this problem. Examination of their answers to......(cont. pg. 131)
## Table I

**A.5 ANALYSIS OF FIRE PROBLEM**

(a) Reasons why child thinks fire is 'alive'

<table>
<thead>
<tr>
<th>Description</th>
<th>Characteristics</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>Spontaneous movement</td>
<td>30</td>
<td>18</td>
<td>48</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Warm</td>
<td>8</td>
<td>3</td>
<td>11</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Coloured, gives light</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Makes noises</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Behavioural</td>
<td>Causes pain, fear</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Functional</td>
<td>Appears to grow</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>58</td>
<td>32</td>
</tr>
</tbody>
</table>

(b) Further reasons why fire is 'alive'

<table>
<thead>
<tr>
<th>Description</th>
<th>Characteristics</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Descriptive</td>
<td>Movement</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Warm</td>
<td>12</td>
<td>9</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Coloured</td>
<td>8</td>
<td>4</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Makes noises</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Behavioural</td>
<td>Causes pain</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Functional</td>
<td>Grows and reproduces</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>'Eats organic material</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Excretes wastes - CO₂, smoke, smells,</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>'Respires'- combusts C+O₂, releasing energy</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Dies</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Environmental</td>
<td>Affected by environmental conditions</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>49</td>
<td>35</td>
</tr>
</tbody>
</table>

(c) Reasons why fire is not alive

<table>
<thead>
<tr>
<th>Description</th>
<th>Characteristics</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passive</td>
<td>Have been told</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Not seven characteristics</td>
<td>11</td>
<td>11</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Structural</td>
<td>Not cells, or complex structure</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Definition of fire-organic combustion</td>
<td>9</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Made by man at will, from dead things</td>
<td>3</td>
<td>4</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Functional</td>
<td>Not normal growth substance curve</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Can't get own food</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Doesn't require energy to maintain complex processes</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Behavioural</td>
<td>No intelligence, self-controlled responses, sensitivity</td>
<td>7</td>
<td>6</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>No defence mechanisms</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Environmental</td>
<td>Temperature too high for life to exist</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Water destroys it</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Solar energy is a fire and is integral to life</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>47</td>
<td>33</td>
</tr>
</tbody>
</table>

TOTAL: 80%
A.5 (c) showed that only one student (No. 46) also gave a highly original answer, placed in the environmental category in A.5 (c). Another explained in A.5 (c) that fire was not cellular. The remaining six highly analytical students in A.5 (b), answered A.5 (c) in vague terms of not showing the traditional seven characteristics. As one student remarked in 5 (c)

'I've almost convinced myself above that it is! However I was taught a pneumonic at school, GRINDEM, and fire doesn't fulfil all these characteristics'. (No. 9)

Responses to an external stimulus (i.e. the traditional 'irritability'), was totally absent in answers to A.5 (b) apart from the single, rather vague: 'affected by conditions'.

Answers in A.5 (c), i.e., 'why is fire not alive' were interesting for several reasons:

(i) The simple structural reason, the absence of cells, was used by only seven students.

(ii) 'Intelligence', 'consciousness', 'thought', and 'control of one's responses' go far beyond the traditional characteristic 'irritability'. Piaget (1973) deduced that the child's notion of consciousness grows out of the earlier notion of life. The observations reported here follow his smaller distribution, with 20% of all reasons in A.5(c) in this category. These reasons strongly suggested an anthropomorphic 'definition' of life which includes a nervous system possessing a brain, giving the ability to think and reason.

(iii) The largest group of reasons were the 35% listed as 'passive'. These also represented 32% of all students' answers in this part of the problem. Students most commonly said: 'fire doesn't fulfil the seven characteristics of living organisms', even after they had shown that fire in fact virtually does fulfil these characteristics in the preceding section! Six students only offered: 'I was taught it at school' in A.5(c).
(iv) Six students gave highly original answers, which showed considerable creative thought (Guilford 1967, Hudson 1966). When I came to group all the listed reasons into 'biological' categories, these six answers all had in common a reason involving a component of the environment (water, temperature, solar energy). I therefore called this category 'environmental'. The following extracts include these six students' reasons:

'...and it can be extinguished by water....' (nos. 13, 43, 46)

'...and because no life could be supported at such high temperatures....' (no. 31, 52)

'...without "combustion" of one sort or another, be it on the sun or in the human body, life cannot exist, as a fire is very closely equated with combustion it must be an integral part of life. Fire (solar) is the life-giving-force.' (no. 26)

Upon further examination, these six students had only given simple 'descriptive' reasons in A.5(a) and (b) of this problem — i.e. none had shown the high degree of analysis in A5(b) discussed above.

There were other instances of originality. In A.5(b) one student wrote that 'fire could be said to die'. This seemed a straightforward characteristic application until she added 'because it can be killed by smothering or starvation' (no. 49). This anthropomorphic statement may be considered a creative answer.

These observations are insufficient to draw any conclusions about the occurrence of creative thought, which is beyond the scope of this thesis. However they are recorded in Chapter 8.5, to add to the picture of the nature of students' learning styles.

At the end of the written task I asked the students: 'Which question(s) did you find particularly thought-provoking or challenging?' The fire problem was mentioned by 71% of all students (20 HB + 17 NS = 37). During interviews several students commented: 'I have never thought of it like that before', and 'those questions were strange to the point of difficulty'. This suggested that unfamiliar problems involving biological concept application were a new experience for many students.
Table II  A.6 ANALYSIS OF THE MARS PROBLEM

<table>
<thead>
<tr>
<th>Evidence suggesting life:</th>
<th>HB (32)</th>
<th>NS (20)</th>
<th>TOTAL (52)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{ Organisms</td>
<td>15</td>
<td>6</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>Organic material</td>
<td>18</td>
<td>14</td>
<td>32</td>
<td>23</td>
</tr>
<tr>
<td>(DNA, protein,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decomposition)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{ Spontaneous movement</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{ Gases</td>
<td>12</td>
<td>8</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Water</td>
<td>18</td>
<td>12</td>
<td>30</td>
<td>22</td>
</tr>
<tr>
<td>Temperature/light</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Human</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Habitation/cultivation</td>
<td>7</td>
<td>8</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>Experimental</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{ Culture/controlled</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>{ Keep an open mind</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

This question showed some unexpected findings:

(i) The 'organisms' group (15%) includes microscopic size, and up to 'little green men'. As one student pointed out: 'the only conclusive proof of life would be to capture your own Martian'.

(ii) The presence of water was considered essential in supporting life by 20% of all reasons (in thirty students). A few students added 'or some other fluid medium'. Similarly oxygen, or other biologically active gases were given as evidence for life. Two other students advised: 'keep an open mind — life may be very different over there'.

(iii) Two main kinds of experiment were described: (a) Culture in controlled conditions. This included incubation of soil samples with biologically active gases (O₂, CO₂, H₂5), uptake of C¹⁴, and growth on nutrient cultures. (only five students included this type of experimentation in their answer). (b) Chemical analysis for organic material. Glucose, proteins, DNA, carbon, chlorophyll and decaying material were variously mentioned and together accounted for nearly one quarter of all 'evidence suggesting life'.

(iv) A group of reasons listed as 'human' strongly suggested very intelligent life, 'groups of settlements', 'constructions', 'methods of
'communication', 'cultivation of food' were included, together with a non-specific 'signs of habitation' and 'burrows'. 'Footprints' and 'tracks' were also included in this group.

It should be pointed out that this question was not answered in jest. After the Fire problem, this question accounted for nearly all other students' answer to the question 'Which was the most thought-provoking or challenging question' after the written test. Several students referred to this Mars problem during interviews, admitting that they had not been able to tackle it to their own satisfaction.

Table III  
**TASK INTERVIEW PROBLEMS**

**B.1 ANALYSIS OF THE ROCK PROBLEM**

<table>
<thead>
<tr>
<th>(a) Is it alive now?</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Touch — movement</td>
<td>12</td>
<td>10</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Touch — texture</td>
<td>16</td>
<td>8</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Function</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiration O₂/CO₂</td>
<td>12</td>
<td>10</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Seven characteristics</td>
<td>16</td>
<td>6</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>Moisture</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

| (b) Is it dead? |     |     |       |    |
| Structure        |     |     |       |    |
| Gross structure  | 12  | 4   | 16    | 24 |
| Cellular         | 12  | 5   | 17    | 26 |
| Chemical analyses:- |     |     |       |    |
| organic          | 5   | 7   | 12    | 32 |
| other            | 6   | 3   | 9     | 9  |
| C¹⁴ dating       | 3   | 1   | 4     | 6  |
| Decomposition    | 5   | 3   | 8     | 12 |

| (c) Is it non-living? |     |     |       |    |
| No cells           | 12  | 6   | 18    | 47 |
| No gross structure | 3   | 1   | 4     | 11 |
| No organic chemicals | 7   | 5   | 12    | 31 |
| No seven characteristics | 2 | 2 | 4 | 11 |

| (d) Other comments |     |     |       |    |
| Ask an expert     | 1   | 1   | 2     |    |
| Difficult to define life | 4 | - | 4 | 6 |
The rock problem focused students' attention onto experimentation, for right in front of them sat a totally unfamiliar object. Further, this problem required careful analytical reasoning to distinguish between all three possibilities — alive, dead or non-living.

(i) Alive?

Instinctively thirty-nine (75%) students attempted to touch it. They were prevented from doing this, and asked what touching it would tell them. Two reasons were given, one being in terms of 'movement', the other 'texture' (hard/soft, warm/cold). Together these two reasons accounted for half of all observations to determine if it is alive — i.e. qualitative, non-scientific grossly inadequate reasons. Moisture, either on the surface or internally if it was cut open, was mentioned by five students. To test for respiration, usually by gaseous change in a closed environment was given by twenty-two students (42%), and accounted for a quarter of the observations to decide if it is alive.

(ii) Dead?

This proved the most difficult part of this problem. Several students tried to think of a single test to 'prove' death, but could only come up with 'decomposition and decay'.

'I'd take it to a research lab. and ask the experts to classify it. If it's living it would breathe, feed, move, excrete. If none of these occurred it would be non-living. Dead is hard, there would also be some decay, not if it's non-living.' (no. 45).

This example also illustrates the difficulty many students had in keeping two differential tests in their minds simultaneously. They were required to distinguish between 'alive and dead' and 'dead and non-living'. This was too much for several students and their reasoning ended up as distinguishing between 'living and non-living', as is shown by the illustration above.
This confusion was also present in the use of 'cells' as a distinguishing characteristic. Thus a student who was supposedly distinguishing between 'alive and dead' and suggested 'look at a microscopic section for cells' had, in fact, slipped into a 'living or non-living' distinction.

A complete analysis of the number of students who mentioned cells shows the frequency of this problem.

<table>
<thead>
<tr>
<th>Cells</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) dead/non-living</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>(b) dead</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>(c) non-living</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

Six of the seventeen students who used cells as a criteria in part (b) of this problem used it inaccurately as a test for 'death' (group b). Those seven students (c) who used the absence of cells as evidence for 'non-living' were scientifically sound in their reasoning, as were the eleven students (group a) who used cells to distinguish dead/non-living. Their problem was how to distinguish alive/dead, other than 'movement'.

(iii) Non-living?

The two main observations, (accounting for 80% of all reasons) were the absence of cells and the absence of organic chemicals. As has been described under 'Dead?', either of these tests most accurately discriminates living/non-living, and the 'living' group needs further testing to determine alive/dead.

During these interviews four students commented that they did not have a clear definition of life. They had first realised in the written test, some two weeks earlier, and had not resolved this yet to their own satisfaction.
Table IV  B.4 ANALYSIS OF THE WEB PROBLEM
(The numbers refer directly to students, as they gave only one answer).

<table>
<thead>
<tr>
<th>Interpretation of 'adages'</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Food chain</td>
<td>13</td>
<td>11</td>
<td>24</td>
<td>51</td>
</tr>
<tr>
<td>(b) Vague dependence</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>21</td>
</tr>
<tr>
<td>(c) Evolutionary (to man)</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>(d) Sociological</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>(e) Structural</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

So why does 'life depend on green plants', or what is meant by 'a web of life'?

(a) Half the students interpreted these sayings in terms of a food chain. However only nine students (19% of total) mentioned harnessing solar energy, or photosynthesis as the reason why green plants are crucial in the food chain. These students all put the sun at the centre of the web, the food chains becoming the 'spokes' and the 'rungs' becoming trophic levels.

The other students all placed plants in the centre of the web. Perhaps the question too heavily cued them, or perhaps photosynthesis was too obvious to mention — I was not able to distinguish this.

Of the nine students mentioning photosynthesis, six of these also mentioned that this action of plants gave vital oxygen as a by-product, and that plants were essential in synthesizing nitrogen-containing organic compounds (amino-acids) from inorganic nitrogen.

(b) Those listed as 'vague dependence' are illustrated:

'everything (including us) is dependent on other things and other things are dependent on us.' (no. 2)

This anthropocentric view was also suggested in a 'plants in the service of man' answer:

'plants produce organic compounds other creatures need because they can't synthesize them themselves'. (no. 8)

(my emphasis).
(c) In terms of evolution, students compared the web to the increasing complexity of life on earth, with microscopic life (or, for one student the DNA strand) in the middle, and primates or man on the outermost rung.

(d) Sociological interpretations were in terms of:

'life is very complex, there's not a linear relationship between birth and death' (no. 31)

'life has guidelines and boundaries that limit it, e.g. lifestyles'. (no. 49)

(e) Structural interpretations were interesting:

'a web has a structure of main branches or it would collapse, everything is dependent on other living things and if you kill some you'll affect others and alter the balance, and have to re-organize. The threads could be climatic factors.' (no. 25)

6.3 DISCUSSION

Throughout these problems, no difference was observed between the Human Biology and Nursing Studies students. This set of questions highlighted the diversity of students' approach to problem-solving. The difficulty many students had in tackling the problems was not lack of knowledge, but in being able to use their knowledge. Answers to all these questions clearly demonstrated that these students have 'learnt' the traditional 'seven characteristics' — growth, reproduction, respiration, nutrition, excretion, irritability and locomotion — as defining living organisms. When faced with an unfamiliar object, the single characteristic of locomotion, or more simply 'movement' pre-dominated many answers. Many years ago Piaget reported this as the earliest stage in the development of animism in young children. What an indictment of two years of A-level Biology!

This line of thought was extended from movement into animal life as being distinctly different (and 'more alive') than plant life. This was almost inevitable due to the teaching of the seven characteristics which are so heavily orientated towards complex multicellular animals.

In all the questions there occurred reasons which associated life with
"consciousness". In the fire question one student answered in 5(c)

'I can't conceive a life form without a certain level of
intelligence'. (no. 4)

another wrote:

'fire can't perceive or think, as we think of life' (no. 23)

another:

'it has no knowledge or consciousness'. (no. 30)

These seemed illustrations of an anthropomorphic view of the world.

Moreover, these reasons suggested life defined in an "operational"
definition of the social and ethical consideration of, rather than
the mere presence of, the basic biological characteristics. This
touches on the fundamental ethical problem of the medico-legal world,
i.e. can human life be defined in terms of a "quality of life" rather
than a mere "vegetable" state, and so lead to an acceptable definition
of "human death"?

The essential dependence of all life, including human life, or
energy flow in the biosphere emerged in only a minority of students' reasons. This was a minor component of this study and possibly more focused questions might have given different results. It was disturbing to find students stating that plants existed only for the benefit of man and higher organisms. Without question, man is seen as the dominant and most important species living on earth today. Whilst this is undoubtedly so if one uses the impact on the biosphere as the criterion, it is perhaps not so convincing if one uses the essential first step in the steps of evolution (Appendix II), i.e. the diversity of individuals and species, adapted to the diversity of habitats on earth. For on these criteria the insect species are so ubiquitous that it is difficult to imagine an environmental change which would totally select against all insects.
Implicit in many of these students' answers is the idea that organic evolution has reached its ultimate creation, with the creation of Man. There is no biological evidence whatsoever to suggest that this is so. The more obvious kind of evolution, cultural evolution, is in addition to the slow process of change in our natural environment, which determines evolution by natural selection, and the continuation of life on earth. It is ironic that, despite the explosion of knowledge and technology, man is not yet able to define the concept of 'life'.

6.4 SUMMARY

1. Four open-ended problems focusing on the characteristics of life were given to fifty-two first year Human Biology and Nursing Studies students, two in a written format and two in a task-interview.

2. The predominant criteria to distinguish alive/dead were movement, warmth and respiration, in both a familiar object (fire) and unfamiliar objects (rock, Martian life). These relate far more to animal rather than plant life, and are similar to Piaget's earlier stages of animism.

3. An extension of animism to life associated with intelligence occurred in both the Fire problem (18% 'Fire has no intelligence therefore is not alive') and in the Mars problem (11% 'signs of advanced habitation').

4. Students had greatest difficulty working out a satisfactory test for 'death'. Both signs of decay, and C\textsuperscript{14} dating were suggested. In using the 'absence of life' as the criteria, the majority of students used the absence of movement.

5. Only 19% of students explained why life depends on plants in terms of photosynthesis. It is possible that students considered this self-evident.
CHAPTER 7

STUDENTS' PERCEPTION OF TIME-SCALES AND THE RATE OF CHANGE

7.1 THE CONCEPT OF TIME-SCALE

Understanding 'time' to most people means merely 'can you read a clockface?' Events of the present are measured with a linear scale, where the time-interval is constant. If it is hard to define 'time', it is even harder to 'teach' the concept of time. When dealing with extremely large time-scales, such as the geological age of the earth, a sense of time is almost incomprehensible. Millions of years are blocked into distinct 'eras'. In considering the evolution of life on earth, geological periods are used. A million years is a different order of magnitude than any 'generation-time' or even 'many' generations of a species, important in a biological dimension. There have been various attempts to give students an appreciation of the huge time-scale of life on earth.

One of the most common is to draw an analogy with a year. Thus if we represent the whole period of the earth's history (~4,500 million years) as if it had occurred in a single year, starting on January 1st, with midnight on December 31st, as the present time, then the Palaeozoic era (marine fossils with shells/or backbones) would have begun early in November, man-like animals would have appeared at 10.15p.m. on the evening of December 31st, and the whole of recorded human history occupies the last 35 seconds of the year. (Morgan 1972).

In an historical perspective, the present is a brief instant of a continuum which has both a past and a future.

Toffler (1971) tried to demonstrate this for human history by dividing the last 50,000 years of man's existence by an average life-span
of sixty-two years, giving 800. He coined the phrase 'the 800th lifetime of man' being this generation which has lived in the 20th Century. It is in this 800th lifetime that society has moved from an agriculturally based economy, through an industrial economy based on manual labour, to arrive now at a super-industrial, or service economy. Contemporary events are no longer contained by material boundaries, but are instantly communicated round the world. The most significant change in this 800th lifetime, Toffler believed, is man's impact over nature's stabilizing forces in the natural environment: 'for no longer do resources limit decisions, but it is the decision that makes the resources'. In discussing the significance of change to education, Toffler emphasised the need to develop in students a sense of time that not only related to the past, (where 'facts' dominate), but also towards the future, where there are no 'facts', but only 'predictions'.

Organic, or Darwinian, evolution is the continuation of generations of organisms through time, in a slowly changing environment. It is dependent on the low spontaneous mutation rate of genes to create the diversity of individuals on which the environment exerts a selective action. Thus the frequency of genes in a gene pool, and the resulting proportion of characteristics in a population, change with time, dependent upon the rate of change of the environment. This relationship is shown diagrammatically in the concept map of evolution (Appendix II). 'Time' itself is an independent variable, (neither directly affecting, nor being affected by other variables), therefore the important question in evolutionary terms is not 'What is time?' but rather 'How fast is the rate of change?'.

Cultural evolution has been defined as the transmission of the record of human civilization — i.e. man's heritage. Transmitted by language, or as Dawkins (1978) has coined 'memes', instead of genes, cultural evolution occurs on a vastly shorter time-scale than organic
evolution, in hundreds rather than millions of years. Using Toffler's 800th lifetime, the explosion of knowledge that has occurred in this lifetime, means that cultural evolution is now significant within a single generation.

The need to understand the two time-scales involved between Darwinian and cultural evolution are due to the impact of man on the biosphere. The major factor of this is the exponential growth of the human population. The global human population first reached one billion (one thousand million) in 1830, by 1950 it was two-and-a-half billion, by 1972 it had added another billion. It is now predicted to double in about thirty-five years. This has major repercussions on the rate of material resource depletion, food production, water and atmospheric pollution, soil conservation and energy consumption. (Mesarovic et.al 1975).

The scientific achievement of harnessing the earth's non-renewable energy resources on a world-wide scale has occurred this century. Currently global energy consumption is doubling in ten years (Meadows et al. 1972). Nuclear fusion, or breeder reactors are not in large-scale development, fission reactors also have limited fuel resources. The energy crisis of the early 1970's was the first taste for the Western world of the importance of energy in our daily lives.

Conservation, defined as 'the wisest use of resources to enable future generations to enjoy life on earth', emerged as a public issue in the mid-1960's, largely due to the threatened extinction of several species of fauna (e.g. Carson 1959, Commoner 1973), in the U.S.A. (Usher 1973) Environmental studies programs, combining biological, geographical, chemical and socio-economic principles appeared in schools in the 1970's.

In pilot studies of tertiary students' understanding of evolution by natural selection, (Chap. 3), several points of misunderstanding were
evident. One was the confusion between changes seen to occur in one generation, and changes occurring over many generations. Many students did not seem to appreciate that '20 years' means many insect generations, but only one human lifetime.

As part of the main study, I included several problems exploring students' perception of time-scales, rates of change, and their perception of future change. As has previously been described, data was collected in both written form and during individual task interviews. In this chapter only the first question, Q.A.3 was in the written test, all others were included in the interviews.

### 7.2 ANALYSIS OF THE TIME-SCALES PROBLEMS

Two tables of biologically important events were designed, requiring the student to fill in corresponding dates. They then had to mark these dates on a time-line, on which only 1978 was indicated.

**A.3**

'During this century, many biological breakthroughs have occurred. In the table below, fill in the dates as accurately as you can. Then mark these events on the time-line (use the letter code if you wish).

<table>
<thead>
<tr>
<th>EVENT</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Oral contraceptives developed</td>
<td>A ----</td>
</tr>
<tr>
<td>B. Penicillin discovered</td>
<td>B ----</td>
</tr>
<tr>
<td>C. First 'test-tube' baby born</td>
<td>C ----</td>
</tr>
<tr>
<td>D. First human heart transplant</td>
<td>D ----</td>
</tr>
<tr>
<td>E. First Atomic Bomb exploded on Japan</td>
<td>E ----</td>
</tr>
<tr>
<td>F. You were born</td>
<td>F ----</td>
</tr>
</tbody>
</table>

---

In this problem the events were all of this century, and a simple linear scale (1" = 10 years) can be fitted on the time-line.

(Note: Item A.3 D. 'First human heart transplant' was omitted in error during final production, resulting in a gap in the otherwise roughly equidistant points on the scale)
'Fill in the dates as exactly as you can in the following table then mark their positions on the time-line below.'

<table>
<thead>
<tr>
<th>EVENT</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The start of recorded human history,</td>
<td>A----</td>
</tr>
<tr>
<td>B. Leeuwenhoek's discovery of 'little animals': the first</td>
<td>B----</td>
</tr>
<tr>
<td>observation of bacteria under the microscope.</td>
<td></td>
</tr>
<tr>
<td>C. Charles Darwin's hypothesis of 'Survival of the fittest'</td>
<td>C----</td>
</tr>
<tr>
<td>D. Watson &amp; Crick's model of the structure of the DNA molecule</td>
<td>D----</td>
</tr>
<tr>
<td>E. The human population is predicted to double from 1972 figure</td>
<td>E----</td>
</tr>
<tr>
<td>$(3,500 \times 10^6)$ in:</td>
<td>F----</td>
</tr>
<tr>
<td>F. The birth of Christ:</td>
<td></td>
</tr>
</tbody>
</table>

---

1978

This second time-line problem was given during the task-interviews. (I switched off the tape-recorder as I found all students worked quietly).

As encouragement I filled in F. I explained two events more clearly:

B.6A 'By this we mean when man first started leaving written evidence of himself, e.g. as cave drawings.'

B.6E (I re-phrased). 'In 1972 the human population was 3,500 million, or $3\frac{1}{2}$ billion. When do you think it will reach 7 billion?'

Many students looked aghast at this problem and emphasised that they really had no idea, they were only guessing. I answered that 'life is full of reasoned guesses' and occupied myself putting away their written tests, leaving them free to work.

When they came to mark the dates on the time-line, (depending on their dates in A and E) they had considerable difficulty. The most efficient scale to use for this problem is a logarithmic one. One of the purposes of this problem was to identify those students who were not familiar with such a scale.
RESULTS

The two groups of students, Human Biology (HB) and Nursing Studies (NS) are reported separately throughout. I have altered the order of events in Table I, A.3, to read from the present progressing backwards in time.

Table I A.3 BIOLOGICAL EVENTS THIS CENTURY

<table>
<thead>
<tr>
<th>C. The first 'test-tube' baby</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>* 1978</td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A. Oral contraceptives</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1910 - 1939</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>1940 - 1949</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>* 1950 - 1959</td>
<td>17</td>
<td>6</td>
<td>23</td>
<td>44</td>
</tr>
<tr>
<td>1960 - 1969</td>
<td>9</td>
<td>8</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>1970 -</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>E. Atomic bomb on Japan</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940 - 1944</td>
<td>9</td>
<td>3</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>* 1945</td>
<td>16</td>
<td>11</td>
<td>27</td>
<td>52</td>
</tr>
<tr>
<td>1946 - 1949</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1950 - 1959</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1960</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Penicillin discovered</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1870 - 1899</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>1900 - 1909</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1910 - 1919</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>* 1920 - 1929</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>1930 - 1939</td>
<td>7</td>
<td>6</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>1940 - 1949</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1950 - 1959</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Don't know</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

(Note: time-intervals are irregular, to represent results most concisely)

* denotes time span containing correct date
Students' time-lines were checked for accuracy. This varied quite surprisingly. The majority of students clearly marked a scale off first on the line, marked the scale and then indicated the position of the letters. These were classed as GOOD on linear scale.

A few students had to extend the line in order to include all their dates. They did not mark a scale, but their results were accurate, indicating they had used a ruler. They were classed as MODERATE on linear scale.

Several students obviously used no scale of measurement at all, but focused on the relative (and qualitative) order of the dates. They were classed as POOR on linear scale, (although it is possible that they misinterpreted the degree of accuracy required in the question).

Table II shows the distribution of students into ability to use a linear scale:

<table>
<thead>
<tr>
<th></th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>24</td>
<td>15</td>
<td>39</td>
<td>75</td>
</tr>
<tr>
<td>MODERATE</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>POOR</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

Table III shows the results of the 'logarithmic' task-interview scale, Q. B.6. The dates were already in chronological sequence in the question.
Table III  B.6 RESULTS OF LOGARITHMIC TASK INTERVIEW SCALE

<table>
<thead>
<tr>
<th>Time Interval</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Recorded human history</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 x 10^6 - 15 x 10^6</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>7 x 10^6 - 1 x 10^6</td>
<td>8</td>
<td>2</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>500,000 - 100,000</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>* 50,000 - 20,000</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>* 10,000 - 5,000</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>4,000 - 1,500</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>1,000 - 200 B.C.(+ AD15)</td>
<td>3</td>
<td>2(+1)</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Don't know</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
<tr>
<td>B. Bacteria under microscope</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* 1600 - 1699</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>1700 - 1799</td>
<td>11</td>
<td>6</td>
<td>17</td>
<td>33</td>
</tr>
<tr>
<td>1800 - 1849</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1850 - 1899</td>
<td>12</td>
<td>7</td>
<td>19</td>
<td>36</td>
</tr>
<tr>
<td>1900 - 1920</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Don't know</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
<tr>
<td>C. Darwin's 'survival of the fittest'</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1700 - 1750</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>1800 - 1849</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>* 1850 - 1869</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>1870 - 1899</td>
<td>9</td>
<td>4</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>1900 - 1930</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>1960</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Don't know</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
<tr>
<td>D. DNA molecular structure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900 - 1929</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1930 - 1939</td>
<td>2</td>
<td>5</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>1940 - 1949</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>* 1950 - 1959</td>
<td>15</td>
<td>7</td>
<td>22</td>
<td>42</td>
</tr>
<tr>
<td>1960 - 1969</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
<tr>
<td>E. Human population will reach 7 billion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980 - 1985</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>1990</td>
<td>6</td>
<td>2</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>* 2000</td>
<td>11</td>
<td>7</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>2020 - 2050</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>2100 - 2200</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>2500 - 3000</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>5000</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

(Note: time-intervals are irregular, to represent results most concisely)

*denotes time span containing correct date
Time-Line Scale: When the range of answers to B.6 A-E is considered, it is hardly surprising that many students had extreme difficulty in constructing a (linear) scale. The following groups were identified and recorded in Table IV in tabular form.

<table>
<thead>
<tr>
<th></th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logarithmic scale</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Accurate linear scale</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td>23</td>
</tr>
<tr>
<td>Arrow off to left for A, rest accurate</td>
<td>11</td>
<td>4</td>
<td>15</td>
<td>29</td>
</tr>
<tr>
<td>Qualitative order - no scale,</td>
<td>11</td>
<td>11</td>
<td>22</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>20</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

It is possible that those 42% of students who only ordered their event chronologically, but with no scale, did not consider such accuracy necessary in this question.

7.3 DISCUSSION OF TIME-SCALES

These scales clearly show that apart from most recent events, the majority of students have very little idea of the history of biological thought. The further away from the present one goes, the greater the range of inaccuracies. This is now clearly shown in B.6A, and B.6E.

The ability to use scales is of interest for two reasons. The first is that very few A-level students (even with Maths) were able to use a logarithmic scale. (One of the three students who did use it has spent five years in the Army). The other is the group of students in A.3 who focused on the events rather than the scale. These observations have been added to the data on learning styles, Chapter 8.7.

In Q. B.6A it could be argued that students misunderstood 'cave-drawings' (20-37,000 BC) and instead identified written records of civilization (i.e. ~10,000 BC). Certainly two peaks were observed, but neither of these correlated with either alternative.
In Q.B6B (bacteria), two peaks were again observed, the more recent one having an unknown interpretation.

7.4 GLOBAL FUTURE PREDICTIONS

Q.B.7 'Can you think of three events that you personally believe are so likely to happen that you feel you could say: "One day, I believe this will happen"'.

(student response)
'Now will you put a date to these three events'.

This future speculation problem followed on from the human population prediction contained in B.6. Many students found this an unusual and a rather difficult task. To students who asked: 'Anything in particular?', I replied 'Anything at all that comes to your mind'.

From this task I obtained about 150 predictions of the future from these students. Individual predictions varied enormously on time from 'I will go out tonight', to 'the sun will burn out in 500 million years'. The time period of greatest interest was the overall group's predictions within their lifetime, i.e. the next 100 years.

RESULTS

One hundred and three predictions were recorded for the next 100 years. These predictions were put on to a chronological time-scale and then divided into the following categories:

Table V

<table>
<thead>
<tr>
<th>Category</th>
<th>NO. OF PREDICTIONS (HB + NS)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific</td>
<td></td>
<td></td>
</tr>
<tr>
<td>space</td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>biomedical</td>
<td>17 (cancer 9)</td>
<td>33</td>
</tr>
<tr>
<td>Political</td>
<td></td>
<td></td>
</tr>
<tr>
<td>government</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>war</td>
<td>24 (nuclear 11)</td>
<td>29</td>
</tr>
<tr>
<td>Environmental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>energy</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>lifestyle</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>food</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>People</td>
<td></td>
<td></td>
</tr>
<tr>
<td>individual</td>
<td>26 (20×1990)</td>
<td>28</td>
</tr>
<tr>
<td>populations</td>
<td>3</td>
<td>29</td>
</tr>
</tbody>
</table>

A more detailed picture is shown in the graph - Table VI on the following page.
### Table VI. FUTURE PREDICTIONS

<table>
<thead>
<tr>
<th>DATE</th>
<th>1980</th>
<th>2000</th>
<th>2020</th>
<th>2040</th>
<th>2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>years after present</td>
<td>+20</td>
<td>+50</td>
<td>+70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### SCIENTIFIC
- **SPACE**
  - Land Mars
  - Interplanetary flight + contact
- **BIO-MEDICAL**
  - Pill cancer mult. scl. human in organ
  - Bact. cult. anti-viral sheep grafts
  - Antibiotic end disease

#### POLITICAL
- **GOVERNMENT**
  - Union dominated communist world
  - UN United world
- **WAR**
  - Israel Russia/Iran nuclear war
  - Germany S.Africa N/China nuclear war

#### ENVIRONMENTAL
- **ENERGY**
  - Crisis fusion
- **LIFESTYLE**
  - Computerized society automated life
  - Car x pollution air/H2O
- **FOOD**
  - Marine farming famine

#### PEOPLE
- **INDIVIDUALS**
  - Degree family die
  - All friends dead
- **POPULATIONS**
  - ZPG species
In the Scientific group, some predictions (especially interplanetary flight and cancer cure) occurred throughout the time-period. On the graph the earliest date was used. In the environmental group, predictions of energy crisis and alternative energy sources was included under Energy; automated life, banning cars and pollution were included as Lifestyle; and famine or alternative food supplies recorded under Food. Under People, predictions relating to 'family', 'get a degree', were listed as Individual, and population estimates or 'species dying' listed under Populations. Rather strikingly, after the year 2000 AD there were no 'individual' predictions at all until they died, at about 2050 AD. This was in contrast with non-personal predictions. Of all the predictions listed in Table V and its corresponding chronological graph Table VI, the virtual absence of environmental predictions is the most striking feature. These 12% are described in further detail below.

Environmental

(a) The 4 'energy' predictions included 3 energy crisis between 1990-2000, and one who predicted the introduction of nuclear fusion in 1995. (In discussions following the rate-of-change graph, Q. B.9, one other student mentioned that solar power 'must come in').

(b) The 3 'lifestyles' predictions contained 2 computerized society, 2 mentioned that another form of transport than the car will need to be found (in 2000, and 2050!) and one student in the entire group, predicted that there will be major air and water pollution in their lifetime (2060).

(c) Two of the three 'food' predictions were 'massive famine and starvation (by 2010) and one student predicted that we will be harvesting food from the sea by 1990.

Political

In contrast to this, the political future scene was one of catastrophic change. National political predictions (e.g. Shah overthrown, change
in British Government) occupied the time until 2000 and then were replaced by global warfare, of which nearly half predicted nuclear war.

Scientific

Scientific achievement was equally divided between space technology and the biomedical field. Since the latter is the area that the majority of these students wish to make their career, I was particularly interested in their predictions.

The most common cure was for cancer, and this accounted for half of all these predictions. They occurred throughout the next 80 years, so the graph records only the earliest date, 1990. Most of the other predictions describe research of today, e.g. organ transplantation, bacterial hormone cultures, a male contraceptive pill and a cure for multiple sclerosis. One prediction of a human foetus being routinely implanted in another mammal, such as a sheep and an anti-viral antibiotic were not predicted within the next 30 years! Only one student believed we will be able to cure and therefore eliminate disease, and that this may be achieved by 1990.

The extreme conservation in these predictions is further reflected by omissions. No student mentioned understanding the mind, in mental disorders, or other diseases arising from a stressful life. Surprisingly, circulatory and cardiac diseases, one of the major causes of death today, were not mentioned. (This correlates well with their own predicted cause of death, in Table VIII.) The rare individual instances of optimism have been circled. Predictions beyond the next 100 years continued the global pessimism, with nuclear war, space travel, artificial environments, a new ice-age, and some students predicting human extinction, the end of the world, and finally the burning out of the sun. The unstable social environment contained in these
predictions is a sharp contrast to students' personal future forecasts in the next section, 7.5.

7.5 PERSONAL FUTURE FORECASTS

Q. B.8 B ____________________________ D

'If you saw this line as representing your life, between B, your birth, and D, your death, where would you put yourself on it right now?'

(mark)

'What figure did you have in mind for D, to mark that position?

(age given)

'That gives you about (50) years. What would you like those 50 years to contain for you, or what do you think they will contain, whether you like it or not.'

This question focused students on their own lives, either a possible or probable future. Additional details were their predicted average life-span for their generation, predicted age of retirement, and likely causes of death.

Table VII

<table>
<thead>
<tr>
<th></th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-60</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>60-69</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>70-80</td>
<td>27</td>
<td>11</td>
<td>38</td>
<td>76</td>
</tr>
<tr>
<td>80-90</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>90-100</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>19</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

Table VII and VIII mirrored the situation as it is today, with the average life-span between 70-80 in 50 year's time, and cardiac disease and cancer being responsible for approximately half of all deaths.

Only 4 students did not mark a scaled \( \frac{20}{70} \) 'now' position on their timelines. Two of these marked themselves well over half-way, but were predicting a 40-year life, (i.e. still scaled); both listed suicide as their most likely cause of death. The other two marked themselves right after B, 'because I have not done anything yet.'
Table VIII  LIKELY CAUSE OF DEATH

<table>
<thead>
<tr>
<th></th>
<th>First reason</th>
<th></th>
<th>Secondary</th>
<th></th>
<th>Comb.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HB</td>
<td>NS</td>
<td>TOTAL</td>
<td>HB</td>
<td>NS</td>
<td>TOTAL</td>
</tr>
<tr>
<td>Heart,</td>
<td>5</td>
<td>6</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Cancer,</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Disease,</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Old age,</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Accident,</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Stress/suicide,</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>War,</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Starvation,</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>39</td>
<td>19</td>
<td>58</td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Careers

The following table shows the distribution of those students who mentioned retirement:

Table IX  THE PREDICTED AGE OF RETIREMENT

<table>
<thead>
<tr>
<th></th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-59</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>60-64</td>
<td>7</td>
<td>7</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>65-70</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>will retire, no date,</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>will not retire,</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>19</td>
<td>40</td>
<td>100%</td>
</tr>
</tbody>
</table>

The table shows that the largest group still predicts a 60-65 age of retirement, as it is today. Seven students emphatically stated that they did not want to retire. This will be further developed in 7.6 below.

One job or several.

The majority of students' personal forecasts were a sketchy 'degree, get a job, travel, marry and have children, retire to relax with hobbies, and have a happy, peaceful life'. My original hope to identify those who described their life sequentially and those who gave a more holist account was not possible with such vague answers. One difference emerged between
the two groups in describing their career. Most of the HB students were extremely vague about their career, and in general spoke only of a job. One student even remarked that he would be ready to retire 'after 30 years in the same job'. Only 3 HB students mentioned a 'varied' career. In contrast, nearly half of the NS students (9) clearly described a varied or branching career, within the nursing profession. This included experience in wards, specialized fields such as theatre or midwifery, administration and then more socially-orientated work such as district-nursing or welfare in their later life.

The picture which emerges from 7.5 is one of a personal life very similar to that of today. What a contrast between the unchanging, optimistic personal forecast and the tremendously changing pessimistic global predictions of 7.4 ! Eleven students (21%) actually spoke of travelling abroad in the time they themselves had predicted nuclear warfare! This suggests that many students found it difficult to hold 2 time-scales in their mind simultaneously. These results are interesting in the light of studies of children's development of 'notions of time' reported by Piaget (1946) and Werner (1948).

Both anthropological and child-developmental studies showed that children discriminated between local, or personal time and universal or impersonal time. As children's thought developed, attention shifted from personal time to the more abstract, impersonal time. According to Piaget this more abstract conception of time had two main structural components; (a) the grasping of the temporal order of succession, and (b) the grasping of the number of equidistant intervals between successive points in time. Thus Piaget explained the development of the concept of time in terms of the concept of number and order.

The results reported above, however, involved 18 year-old students. In 1972, Piaget formally acknowledged that his original estimates of the ages most children pass through his levels of intellectual development
were not typical of the general population. Since then, after extensive empirical studies, Renner (1977) has found that only approximately 25% of a sample of American high school students, (mean age = 16.75 years), were at the level of formal operations. The 11 students, (21%) described above may represent a similar level of thought.

Correlation of global and personal future forecasts.

Only 6 students (12%) correlated their personal lives with their earlier global predictions. Five of these qualified their forecasts simply with a 'if there's no war' or 'if nothing intervenes'. The mismatched observations are included in learning styles analysis, Chap. 8.7. One student, however, gave a very thoughtful answer, which I use to complete this section:

'Obviously it depends on the situation, you've got to keep up with what's happening around you, assess it and progress from there. I would like to go into neurology research, in about 10 years time I think my mind will be mature enough. But I said there will be a world war in 1982, so I might not be here! I think you have to keep that in mind in a way, because I am part of the world we're living in, and I've got to take into account that I'm one of those that's going to be involved in whatever's going to happen. So I've got to take these things into consideration and work out my life from there! (no. 17)

7.6 STUDENTS' PERCEPTIONS OF THE OLDER GENERATION'S ATTITUDE TO CHANGE

Following the students' interpretation of the Graph task (B.9) illustrated in Appendix VII and analysed in detail in 8.3, I indicated the blank region 1980-2000 AD on the graph and asked:

Q.B10 'Would you like to comment on the effects of a graph of this sort on people's lives in this region?'

All students predicted that the general trend of the graph would continue, but would have to level out, i.e. not actually hit the axis. A few spoke of the consequences of the silicon chip in creating our increasingly computerized society, with massive unemployment ('chips don't have tea-breaks, or go on strike'). This would lead to increased leisure time. No-one mentioned the possibility of loss of individual
freedom, but believed they could choose to accept or reject new inventions. This was in contrast, they said, to the effect of change on old people.

Detailed analysis of their comments on the generation gap are beyond the scope of this thesis. But since cultural evolution is measured more on a relative time-scale than an absolute one, I include below a selection of extracts, which convey the theme of their attitudes towards the older generation:

'I was in a hospital earlier this year and there were all these old people, just coming in to die, and I thought:"How horrible". I'd rather be out of the way. If I hit a bad day I can think "never mind, there's something better to come" but not them.' (no. 1)

'How do old people enjoy themselves? There's nothing to look forward to in some ways. I've got my whole life.' (no. 25)

'Old people begrudge youth their youth. They can't cope with the pace of life, so they become hostile. They dream of their green fields.' (no. 30)

'There'll be better conditions for them, walking aids, etc.'(no. 30)

'They'll be housed in government housing," for their welfare"'.(no. 3)

'Old ways have become a way of life. They're less susceptible to change, whereas young people are more likely to accept new ideas. Its like when we changed over to new money — young people rarely complained, it was easier in 10's, but old people still stuck with £.s.d. because they'd been brought up with it.' (no. 14)

'For instance, take this digital watch. You don't see many elderly gentlemen wearing them, because they're used to the way they've been doing things for the last 60 years — they're not going to change now. I'd say the changes are going to affect young people more.' (no. 25)

'Younger people find it easier to accept change — you haven't been used to things for 50-60 years. It's age, and its also the time you live in. It'll probably be easier for me, because I've lived with change.' (no. 18).

'Everyone's coming to accept these far-out things — for example in a few years we may be living on the moon, and we're not going to bat an eyelid. The older generation will probably take longer to accept, or not at all. Actually it shouldn't be like that in a sense because they've seen so much change. Perhaps its because they see things around them being destroyed and abused, and they think back to the good old days and the lovely scenery and rather live as they were 20-30 years ago, so keep their memories. At present there's so much going on and such a lot of change and we are accustomed to it. Their generation had the dramatic change in their life.' (no. 51)
'We're living in a changing world. In one life-span from 1900-1980 the rate of technology has been tremendous, in flight, from the Wright Bros. to Concorde. The old don't pay much attention, they let it go over their head, they probably don't want change, or can't cope with change. I could cope, because I can see what it means. We're brought up accustomed to change.' (no. 15)

'There's a danger if people readily accept change without question. I think we need to be more suspicious — Darwin's survival of the fittest.' Look at Fleming and penicillin and Curie with radium. A lot of people wouldn't have dreamed of saying "treat me with it". At the time I think people were a lot more suspicious of it, whereas these days the amount of time taken for them to become known I think is getting much too short. Thalidomide is a classic example. People were told: "this is a good drug, it will clear your headache", but it didn't just do that. With the amount of competition, especially in the drugs market, and inadequate testing, there's much less time on research and people have to be cautious.' (no. 26)

'The difference is in attitude, not in communications. They've been brought up with religion and morals and this affects their whole thinking. Its already changed to some extent, away from religion and an increase in science. The change will be quicker in future, but everyone thinks his own time is the most fantastic, exciting and the most changing. Their parents said changes of last century were so much faster than their parents had told them.' (no. 50)

For these students a changing world has been all they have ever known. They described their acceptance of such change, and indeed forecast massive global change within their own lifetime (7.4). They also, in general, showed awareness of the difference between previous generations, whose world was more stable, and their own generation, (although as a few above quite rightly pointed out, their parents' generation was the one that lived through the dramatic post second world war change, whereas they themselves have always lived in a rapidly changing world). However, despite their stated acceptance of change, on the parameters measured these students could not predict significant personal change in the future lifestyles of our society.

7.7 DISCUSSION

There is a curious inconsistency in their acceptance of future change. I have described in Chapter 6 how the maturation of concept understanding usually is from an anthropocentric view and progressively
becomes more impersonal and objective. Piaget (1973) called this 'decentration'. For these students' future orientation this seems to have been reversed, for they have described their acceptance of future impersonal, global change before they have in fact described future change with their personal lives (7.5). Further research into the conceptualization of the future, with its 'predictions' rather than its 'facts', is strongly suggested by these observations of students' perceptions of time-scales.

Born around 1960, these students are the space-age, genetic-engineering, computer generation. The only global crisis they have experienced has been the 1970's energy crisis. They are part of the minority of our population with the privilege of tertiary biological studies. Not only do they need to be able to understand the steps of evolution by natural selection (Chap. 5), but they also need to see the relationship of the concept of time to this process. Although cultural evolution is a much faster process (Dawkins 1978), as Attenborough (1979) pointed out, there exists no scientific evidence whatsoever to believe that man is exempt from the process of Darwinian evolution. Therefore, since 'a change in the environment' is the trigger of the selective process, an understanding of the rate and direction of environmental change is vital to ensure the continuation of life on earth.

7.8 SUMMARY

1. Dates of major biological events within the past 300 years became less accurate as the time-gap from the present increased.

2. Over 20% of students had difficulty drawing a linear scale. When required to construct a scale for dates including the distant past, and the recent past, 3 students were able to use a logarithmic scale.
3. Global future predictions of the next 100 years were overall pessimistic and described an unstable world. Environmental predictions accounted for only 12%, scientific, political and personal predictions each accounted for approximately 30% of all predictions.

4. Individual, personal future forecasts, by contrast, were optimistic, describing a secure, happy 'normal' life. Age of retirement expected life-span and causes of death mirrored today's figures. This was sometimes in conflict with their earlier global predictions but only 6 students related their personal future to predictions of society in general.

5. Most students believed that the older generation is overwhelmed by the rate of change. They themselves have known change all their lives and so will always be able to accept change more readily. Only 3 students expressed concern about the increasing acceptance of science in our society.
STAGE 3. MAIN STUDY

STUDENTS' LEARNING STYLES
CHAPTER 8

LEARNING STYLES FOR DIFFERENT TASKS

8.1 TERMINOLOGY

As has been reviewed and summarized in Chap. 1.4, many education researchers have recently studied some distinctive differences between students' approach to, and performance on particular tasks. This has loosely been termed their learning style or cognitive strategy. Consistent relevant criteria have been found for different tasks. The problem of giving different sets of criteria a comprehensive 'name' has obviously perplexed many workers and the number of 'dichotomies' has steadily grown. When I identified the essential criteria used to characterize each of these dichotomies, the differences between them became much less apparent. Two major groups of dichotomies remained, one concerned with the student's perception of the task or problem, i.e. how he 'saw' it, the other associated with relating the task to his existing knowledge. As is explained below, I have excluded this second set of dichotomies from those related to 'learning styles'.

(a) Learning styles — the student's perception of the task

In the simplest hypothesis, postulating a single dichotomy, there were two important criteria which all individual sets had in common:

(i) immediately breaking a task or topic into its component parts, and studying them step-by-step, as discrete entities, in isolation from each other and from their surroundings.

In this category Witkin's 'field-independence' (with its 'hypothesis-testing' approach), and his 'articulated style', Pask's 'serialist', Bruner's 'analytic' and possibly Guilford's 'convergent production', all have, as their essential criterion, a 'divided into parts' view. Skinner's model of S-R learning steps (1.1) also suggests this approach to learning. Wertheimer's 'rote-memorizing', Ausubel's
'rote-learning', Marton's 'surface-processing' and Pask's 'operation-learning' have been excluded from this list and are included in the second set of dichotomies. I believe they relate to other parts of the learning process than to the intellectual skill termed learning style (see 2.9 and 8.10).

(ii) an overall view, or seeing the topic/task as a whole, integrating and relating its various subcomponents, and seeing them in the context of their surroundings. In this category are the corresponding pairs to those listed in (i) above: Witkin's 'field-dependence (with its 'spectator' approach) and his 'global' style, Pask's 'holist', Bruner's 'intuitive' and possibly Guilford's 'divergent production'. This category echoes much of the early 'Gestalt' theories (1.1), also the 'lateral thinking', popularized by de Bono (1967). Wertheimer's 'productive-thinking', Ausubel's 'meaningful-learning', Marton's 'deep-processing' and Pask's 'comprehension-learning' have been placed in a separate group (b), below.

When I observed striking differences in students' approaches to various problems, I was also faced with the problem of selecting terms to describe these differences. Initially I used Pask's 'serial-holist' terms, (Pask and Scott 1972) in the pilot studies 3.6, and the first visual-verbal translation task, 8.2). These words seemed to convey the essential difference between the two types of approach. A 'serial' is a story in episodes, each complete in itself but flowing from the preceding one. 'Holist', by pronunciation alone, suggests the 'whole'. I have left my analysis of the first task (8.2), in this serial-holist form to show the development of thought.

This terminology, however, was not so appropriate for the second visual-verbal translation task, (8.3). When the students broke the
graph into its axes it was not as a 'serial'. Of the various words used by others in this field, the two which most clearly described the essential differences between these two examples, (the parts, or the whole), described in this chapter, were 'analytic' and 'holist' styles.

'Analytic' is derived from the verb 'to analyse', defined in the Oxford Dictionary as 'to resolve into its simpler elements by examining the detailed constituents of', 'to find or show the essence or structure of (book, music, etc)'.

'Holist' metaphorically reinforces the essential criterion of seeing a task as a complex inter-related 'whole'. Popper (1957) has described the importance of holism in sociology and all 'biological' sciences, for 'the (social) group is more than the mere sum total of its members'. In extending holism to history Popper included a temporal component to this group relationship.

(b) Level of Integration.

The other common set of criteria, embracing the remaining dichotomies were:

(i) a memorizing approach, with poor ability to integrate or relate new material into a student's own existing knowledge. In this category Wertheimer's 'rote-memorizing', Ausubel's 'rote-learning', Marton's 'surface-processing' and Pask's 'operation' all belonged.

(ii) active integration of, or relating new material to students' existing knowledge (which, by implication includes the real-world). The corresponding pairs were Wertheimer's productive thinking', Ausubel's meaningful-learning', Marton's 'deep-processing' and Pask's 'comprehension learning'.
These were most closely equivalent to the '+' sign in my original model to describe learning. In Groups b(i) and (ii) above, they implicitly suggested 'outcome' as well. Marton and Saljo (1976a) have reported a relationship between 'process' and 'outcome'. This is discussed later in this chapter, (8.10).

In order to distinguish, for my observations, terms describing differences in 'level' without this blurred association of 'outcome', (for this was what I was trying to test), I have used the term 'levels of integration' and have identified 'low' and 'high'.

**Low level of integration:** Student tackles the problem as an isolated task, making no obvious attempt to relate the material contained in the task to pre-existing knowledge,

**High level of integration:** Student actively attempts to relate the problem, task, or new material to existing knowledge or ideas. These may include real-life comparisons. Three qualifications should be recorded, concerning this distinction:

1. Students classed as 'low' may have considered the question only required this level, and may, if specifically directed, have been able to show a high level of integration.
2. 'Levels' may be content-dependent to a much higher extent than are learning styles.
3. In contrast to the equivalence of learning styles dichotomies, the level dichotomies clearly contained a value-judgment, i.e. one was 'better than the other', particularly in terms of learning outcome.

These points are discussed further in 8.10 and 9.3.

This chapter describes the observations of the learning styles and levels of integration of the same biology students as in Stage 2 of this project. Three sets of observations on learning styles included the whole population (8.2, 8.3, 8.4). Several additional observations from various problems analysed in other chapters, also provided incomplete evidence on
learning style (8.5). All these separate results have then been tabulated, student-by-student in Table VII, 8.8, to determine the overall consistency of style and level for a student, across different biological tasks and problems.

The tasks described in this chapter are:

8.2 The first descriptive task — the diagram of Immunity
   (called the 'Immunity' task)
8.3 The second descriptive task — exponential graphical interpretation
   (called the 'Graph' task)
8.4 The hypothesis-testing task — the Rock problem
8.5 Other observations, — the Fire problem, use of examples in discussing older generation,
   time-scales, mismatched predictions.

8.2 THE FIRST DESCRIPTIVE TASK — THE IMMUNITY TASK.

Development of the task

In order to explore the variation in learning style to a task, I developed an unfamiliar biological descriptive task.

During the earlier studies investigating misunderstandings of the concept of Darwinian evolution, held by these first year Biology students, I found frequent misuse of the term 'immunity'. This latter topic is not part of the standard A-level Biology syllabus, and upon checking, I found that only four students had formally studied 'Immunity' previously. This seemed an excellent topic to use to design an unfamiliar problem for these students; it is an active part of biological research today, and forms a subsequent part of their tertiary studies, and students were extremely interested after discussing common misunderstandings of evolution. I prepared a 'concept map' of Immunity (based on Ausubel 1968) (reproduced in miniature on page 167 and in full size in Appendix VII) for overhead projection. To remove all need for 'memorising', I left this diagram on view throughout the task.
Task implementation.

After the completion of the individual task-interviews, in place of a normal lecture, I asked the combined first-year Human Biology and Nursing students for their participation in a descriptive task. The following introduction records the instructions given before they saw the diagram itself:

'I'm going to show you a diagram of the main types of cells involved in Immunity. I want you to study the diagram for a few minutes in order to sort it out in your own minds, and then, when I tell you, I want you to write out your own description or explanation of Immunity, in your own words, as clearly as you can.

The diagram will be on view all the time — this is NOT a memory test! The relationship between various cells is shown by arrows. Solid arrows in general represent the transformation from one type of cell to another. There are two dotted arrows which represent a relationship which is, as yet, not completely understood. I will not speak, or answer questions once the diagram is on, as I don't want to focus your attention in any way.'

The diagram was then shown, and after two minutes they were allowed to begin writing. The written description took twenty minutes to complete.

THE IMMUNE RESPONSE

STEM CELLS (BONE MARROW) → THYMUS

B-CELLS

HELPER T-CELLS

T-CELLS

PLASMA CELLS

B MEMORY CELLS

T MEMORY CELLS

SMALL LYMPHOCYTES

SERUM ANTIBODY

NON-ANTIBODY PROTEINS

NON-CELLULAR IMMUNITY (IMPORTANT IN INFECTIONS)

CELLULAR IMMUNITY (IMPORTANT IN GRAFT REJECTION)
Method of Analysis.

The broad ideas of Pask's serial/holist dichotomy and Marton's deep/surface levels of processing were used to develop criteria appropriate to analyse this task. After inspecting several random protocols, and comparing sample analyses based on Pask's and Marton's criteria by Dr. Laurillard, I selected the following criteria for analysis:

1. **Style**

   **Serialist (S):** where the order of two or more points corresponded to a vertical progression through the map, a letter 'S' (for serialist) was placed in the margin.

   **Holist (H):** where two cells were compared laterally across the map, or one sentence contained points from both types of immunity, the letter 'H' (for holist) was ascribed. Occasionally a level comparison was contained in two succeeding sentences, within the one paragraph. These were also classified as 'H'. Thus by adding the marginal letters, students could be categorised into three groups:

   - Pure S: Using serialist style,
   - Pure H: Using holist style,
   - S + H : Using a mixture of criteria of both styles (henceforth called 'versatile').

2. **Level**

   The content of this task was new to all but four students. On examination of students' protocols, however, I found the answers revealed that, although they had not formally studied this topic before, many students actively added extra detail, knowledge, examples and hypotheses to their 'descriptions', linking this diagram to already existing knowledge. Where students did this, they were classified as 'high' in their level of integration for this task. Other students did not give any additional information or interpretation, or relate the diagram to their existing knowledge in any
way, but described only the explicit points of the diagram. In order to distinguish such students, they were classified as 'low' in their level of integration.

It should be noted that students were only asked 'to describe Immunity in your own words, as clearly as you can', and that some of the students placed into the 'low' category in this task were interpreting my directions in this straight-forward way, and were capable of making links to pre-existing knowledge if they had been specifically asked. Certainly additional ideas were not essential to describe the diagram fully.

This distinction between 'style' and 'level' will be expanded in later discussion (8.10). Using these two sets of criteria, all forty-eight students' protocols were analysed.

The following examples have been reproduced in full, with the marginal analysis showing style and level codes. (+ denotes high level.)

EXAMPLE 1.

Serialist style, low level of integration.

'It seems from the diagram that the way the stem cells of the bone marrow develop leads to either cellular immunity or non-cellular immunity. Considering the former the diagram indicates that these stem cells develop in the thymus where they transform into T-cells. These cells can develop into T-memory cells and possibly (by an unknown developmental path or association) into small lymphocytes. These in turn are transformed into non-antibody proteins. It is these non-antibody proteins and the T-memory cells which constitute the cellular immunity which is important in graft rejection. Other stem cells may develop into B-cells (the diagram seems to indicate that this transformation is not in the thymus). These B-cells can also develop in some way from T-cells via Helper T-cells — the precise mechanism for this is again unknown. Thus here there is a link to what on the first study the diagram shows (to me) as two distinct routes to the distinctive immunities. The B-cells themselves — from either source of development — can transform to either B memory cells or plasma cells. The latter develop into serum antibody which, along with the B-memory cells constitute the non-cellular immunity which is important in infections. (no.30)
EXAMPLE 2.

Serialist style, high level of integration.

\[ S(8) \] 'Non-cellular immunity is the way in which antibodies in the
blood can fight infection.
Stem cells in the bone marrow mature and give rise to B-cells.
These are released into the bloodstream and circulate in the
plasma. When a foreign body, such as bacteria, is encountered,
plasma cells manufacture antibodies which can specifically act
on and destroy the bacteria. Once this specific antibody is
made, a feedback mechanism works, so that the B-cells can
"remember" the mode of manufacture of the specific antibody,
and this is stored in the B memory cells for future reference.

\[ S(7) \] Cellular immunity is the response of the body to foreign
tissue such as grafts and transplants. Stem cells from the
bone marrow can act upon the cells of the thymus gland which
produce T-cells. T-cells are transformed by an unknown
mechanism to small lymphocytes which are within the lymphatic
system. The lymphocytes encounter foreign protein such as a
skin graft, and build up proteins which adhere to the foreign
protein, preventing cell replication. Again, once the protein
has been built up, a feedback mechanism works on the T-cells
and the mechanism of manufacture of the protein is "remembered"
in the T-memory cells.

There also seems to be a correlation between B cells of
non-cellular immunity and the T-cells of cellular immunity.' (no. 31)

EXAMPLE 3.

Holist style, low level of integration.

'Two different routes to explain the immune response. Taking
the stem cells (for example) going in one way through to thymus
cells, and in the other to bone cells. In the process they
have a common type of memory cell, perhaps because of helper
T-cells being between, but in the end give different results.
The thymus cells will be important for graft rejections, and
the bone cells will end being important for infections.' (no. 12)

EXAMPLE 4.

Holist style, high level of integration.

'Stem cells involved in the immune response are produced in
the bone marrow and are the least differentiated cells. Some
of these then pass on to become B-cells whilst the others pass
to the thymus where they are transformed to T-cells. At this
stage in development from the stem cells, the T-cells can be
transformed into B-cells.
From here, though, the function of B-cells is the formation
of plasma cells which produce the serum antibody used in
non-cellular immunity, used in combating infections. On the
other hand T-cells are transformed into small lymphocytes which
produce the non-antibody proteins for cellular immunity which
is important in graft rejection.
Both B and T-cells produce memory cells which will remain in
the body permanently and give the immune reaction to the specific
infection or foreign cells which caused their particular
production in the first place, i.e. production of the serum
antibody or non-antibody proteins, much more quickly to the
foreign bodies far faster than the first time of attack.' (no. 7)
EXAMPLE 5.
Versatile, low level of integration.

'This diagram shows two types of immunity, cellular immunity resulting from non-antibody proteins, and non-cellular immunity resulting from serum antibodies. In both types of immunity the cells producing it arise originally from stem cells in the bone marrow. In the case of cellular immunity, the stem cells develop in the thymus and then into T-cells which from the small lymphocytes of the blood, producing non-antibody proteins. For non-cellular immunity the stem cells develop into B-cells which in turn form the serum antibody-producing plasma cells of the blood. It is thought that B-cells may also be formed from T-cells by way of another type, called helper T-cells. The B and T cells also form B and T memory cells, these however do not have a direct role in immunity of either type.' (no. 25)

EXAMPLE 6.
Versatile, high level of integration.

'When considering the immune response two different types of immunity are taken into consideration. There is non-cellular immunity which is important in infections and cellular immunity which is important in graft rejection. Both types of immune response can be said to stem from the stem cells of the bone marrow. This means that when a foreign body (a pathogen or a tissue graft) enters the body the stem cells are stimulated. In the case of the cellular immunity the stem cells stimulate the thymus to produce T-cells. With the non-cellular immunity the stem cells stimulate the production of B-cells. T-cells have various functions; some exist as T-memory cells to build up immunity, some go on to produce small lymphocytes which in turn give rise to the non-serum antibodies, and some are helper T-cells which help stimulate the B-cells. B-cells have two functions as well, (a) form B-memory cells for subsequent immunity, and (b) stimulate plasma cells to produce serum antibody. Thus we have two types of immunity making up the immune response. (no. 49)

Twenty minutes was given, and, in the belief that all students had finished, the diagram was removed. Subsequently I found that one student had not finished. He asterisked the position in the margin and continued his description, presumably from memory. The change in style, from holist to serialist, with and without the diagram is striking. Note that he still retains his high level of integration despite the change of style. For this task he was classed as versatile. His full protocol is recorded as Example No. 7.
EXAMPLE 7

'Stem cells, from the bone marrow, are in some cases transferred to the thymus and here converted to T-cells, in other cases they will be converted to B-cells. It seems there is a connection by which the T-cells can in turn convert to B-cells. Once these cells have been created for a particular "infection", i.e. the T or B-cells will be specific to one or possibly two similar "infections". Once the introduction of an "infection" to the body the appropriate T or B-cell will be formed and then replicated and in this way get rid of the "infection". Once the "infection" has been cleared the type of B or T-cell used will not disappear but will be stored so that if re-infection occurs there will already be a type specific cell to counteract the infection and so speed up the cure. * The B-cells seemingly are transferred to plasma cells and then on to serum antibodies which possibly can be transferred from individual to individual. There is also an unsure link from T-cells related to lymphocytes and grafting, i.e. cells from one person to another being able to co-habit'. (no. 19) (* overhead taken off)

RESULTS

Using these criteria, identified after examining several random protocols, each student's description was analysed into both 'style' and 'level', and the group results were tabulated. Table I shows the distribution of the twenty-nine Human Biology (HB) and nineteen Nursing Studies (NS) students separately. In the table 'styles' have been denoted as S - serialist, H - holist, and S+H - versatile.

<table>
<thead>
<tr>
<th>STYLE</th>
<th>LEVEL</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Low</td>
<td>8</td>
<td>7</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>H</td>
<td>Low</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>S+H</td>
<td>Low</td>
<td>6</td>
<td>3</td>
<td>9</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>20</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>29</td>
<td>19</td>
<td>48</td>
<td>100</td>
</tr>
</tbody>
</table>

The sex distribution within the three categories of learning styles is recorded in Table I(a). Percentages in the right-hand column are the percentage distribution of the total male or female population in the group.
Table I (a).

<table>
<thead>
<tr>
<th>STYLE</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>% of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>8</td>
<td>10</td>
<td>18</td>
<td>58%</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>S+H</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>39%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>14</td>
<td>15</td>
<td>31</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table II summarizes the number of students using different levels of integration irrespective of style, for the two groups of students. Percentages in brackets are percentages within one group of students.

Table II

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>16 (55%)</td>
<td>11 (58%)</td>
<td>27</td>
<td>56%</td>
</tr>
<tr>
<td>High</td>
<td>13 (45%)</td>
<td>8 (42%)</td>
<td>21</td>
<td>44%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29</td>
<td>19</td>
<td>48</td>
<td>100%</td>
</tr>
</tbody>
</table>

From Table II it is clear that, for this task, the two groups of students were similar in terms of their level of integration, i.e. just over half of each group were classed as low level, and just under half at high level in each group.

Table I shows that within the two basic styles identified for this task, (serialist, holist and versatile), the proportion of students at low and high levels was also similar for both groups, and that half of all participating students described this task in a purely serialist way.
When sex distribution was examined, a difference was found between the proportion of male and female students using different styles. (Table I(a)) Approximately 30% of all male students, and 60% of all female students in the sample population, used a purely serialist style in their descriptions. Such a difference was not significant in the group of versatile students, (using a mixture of styles), 39% of all females and 47% of all male students showing versatility in their perception of this task. Numbers in the holist style were too low to comment.

I was extremely fortunate in having Gordon Pask's willing participation in this task during subsequent discussions. He received the identical instructions prior to the task. His protocol, and my marginal analysis follow, as Example No. 8.

EXAMPLE 8

'Stem cells in the bone marrow give rise to two kinds of protein-based immune reactions, namely one which is important in respect of rejecting grafts (the non-antibody proteins), and the other of which is antibody specific (serum) reaction used in infections. This semi-central system is interesting insofar as:

\( S \) (a) serum cells give rise deterministically to B-cells that have a memory B-cell,

\( S \) (b) give rise to thymus stimulation and (again deterministically to T-cells) these also have memory T-cells

\( H \) (c) whereas in (a) B-cells regulate (in general) certain body production, the determinism is contingent upon a hypothetical relation; through helper T-cells that act upon them.

\( S \) (d) T-cells give rise (only by hypothesis) to small lymphocytes

\( S \) (e) these small lymphocytes are known to produce a collection of non-serum antibodies and it seems that there is at least some deterministic evidence that these give rise to non-serum antibodies;

\( T \) (f) do we know what these are, and

\( T \) (g) what in the world are "helper T-cells", and

\( T \) (h) what is the role of the known-to-exist B-memory and T-memory cells? Are these cells merely "adaptive" (anything in that case has, by specification a "memory" including the cells themselves).

I hardly referred at all to the illustration during the event.'
1. Gaps

A further interesting point arose when protocols were examined for 'gaps' — i.e. arrows or cells which were entirely omitted from students' descriptions. It was striking that none of these gaps occurred in any serialist description. One such gap was the absence of the plasma cell. Examples 3 and 8 (students no. 12 and GP) illustrate this. This particular cell was omitted in three protocols. Another gap (occurring twice) was the arrow linking stem cells to B-cells directly. The following extract illustrates this gap:

'.....Bone marrow cells "develop" into, or even enter the thymus. These thymus cells are then transformed or cause the production of T-cells, which by an unknown mechanism become transformed or cause the production of B-cells via the helper T-cell intermediate; these cells are transformed or cause the production of two cells — the plasma cell and the B-memory cell.' (nos. 6, 26).

A third gap was the omission, by one student, of any mention of memory cells (i.e. the most central part of the diagram). (no. 44).

2. Misconceptions

Not all students who showed a high level of integration made biologically correct links to their existing knowledge:

'In the bone-marrow red-blood cells are formed around the nuclei which are rejected as the RBC leave the bones. These cells without nuclei go to the thymus in the bloodstream — the thymus is a gland producing hormones which cause T-cells.... .....the small lymphocytes need the harmful bacteria to be present so that they can produce the necessary enzymes (proteins) to destroy them — the harmful invading bacteria is taken into the lymphocyte and enzymes work on it within the WBC — probably because the enzymes, if free in the bloodstream might damage the body.' (no. 21, overall classed as versatile, high level).

This student has related the diagram to two incorrect, known concepts, the functional role of the RBC stem cells, and the role of cellular Immunity to bacterial immunity (although the diagram states that Non-cellular Immunity is important in 'infections'). This seems an instance of the development of misconceptions, postulated by Ausubel (1968) and West and Fensham (1974).
3. **Familiarity with topic**

The four students who had studied immunity previously were, not surprisingly, placed into the high level of integration. In their styles two were versatile and one each was H, and S.

4. **Levels of integration**

I have not attempted, at this stage, to quantify the high levels of integration used by students, since such analysis is, I believe, beyond the validity of this particular experimental task. However, in addition to protocols 2, 4, 6, 7, and 8, all of which contain examples of high integration (in different styles), I have included the following extracts which illustrate how different points of the diagram were integrated:

- 'The B-cell system is mainly used for non-cellular immunity meaning they attack bacteria and viruses' (no. 11)*
- 'The memory of the B-cells .. is important to infections, i.e. once immunized (i.e. primary response occurred) to a certain disease, then a second contact with the disease will be of a shorter duration...' (no. 6)*
- 'The thymus gives rise to ... small lymphocytes which become non-antibody proteins (not used in immunization but perhaps are only products of the formation of T-memory cells?)' (no. 37)
- 'There must be a trigger causing bone cells to become stimulated, i.e. change in intra- or extra-cellular environment.' (no. 4)

* (students nos. 6 and 11 had formally studied this topic, nos. 37 and 4 had not).

**DISCUSSION**

This descriptive task, using visual—verbal translation, was a straight-forward task similar to common methods of summarising topics in science subjects. Student interest in the topic itself was high, and the time and industry with which they participated, suggested they did not consider it obscure, irrelevant or tedious. It has resulted in a spectrum of student descriptions. A single dichotomy (such as Pask's, or Marton's) was insufficient to analyse all individual protocols. By combining elements of both these worker's criteria, however, a distinction could be made between learning style, (identifying serialist/holist) and levels of integration (identifying low/high). This then enabled all students' protocols to be categorised.
Learning styles used in this task

The students I have classed as using a serialist style essentially saw the diagram as two vertical columns, with a minor column in between. Many emphasised this point by ordering their description numerically. But this was not NECESSARILY a 'sparse mental picture', or isolated topics' which Pask used to define 'operation learning'. These results highlight the difference between Pask's earlier 'serialist', and subsequent 'operation learner'. 'Serialists' did not NECESSARILY keep to the surface of the topic, without relating to meaning' as in Marton's 'surface-processing.' Conversely, students classed as holist for this task explained by moving laterally at each level of the diagram, drawing comparisons and discussing points more generally. Their description of immunological memory illustrated this clearly. However this style did not NECESSARILY include further insight than was contained in the diagram.

Similarly students who were versatile (i.e. used characteristics of both styles) did not NECESSARILY go beyond the specific content of the diagram. It is difficult to imagine how Marton would classify these versatile students who showed only low level of integration (Example no. 5), or serialist students with high integration (Example no. 2).

Interestingly, students who left 'gaps' in their descriptions were classed as either holist or versatile. No serialist student omitted any points on this diagram.

These observations suggested that this difference in styles was not necessarily sequential or hierarchical, but that knowledge can be progressively learned by quite different approaches even in the earliest stages. If versatility (i.e. the ability to use both these styles) develops later, (and this has not been shown in this single task), it may develop from either direction, as shown diagrammatically:
Levels of integration used in this task

For this task I have identified only two levels of integration:

(i) low level — students who made no attempt to relate any part of the diagram of Immunity to their existing knowledge or to give any further interpretation of the diagram. This corresponds with some of Marton's criteria of 'surface processing',

(ii) high level — students who actively related and integrated various parts of this unfamiliar diagram to their existing knowledge (both correctly and incorrectly), including illustrating their description with examples. This corresponds to some of Marton's criteria of 'deep processing'.

These levels of integration were quite distinct from, and independent of, the style used by students at different levels. In this analysis I have not excluded those four students, known to have studied this topic previously, and those students who used a high level of integration with no formal background. (They have been asterisked in Table VII, 8.8) I consider it unrealistic to exclude these four as, in normal courses, such an occurrence of a diversity of educational backgrounds, experience and interest will always exist. In higher education this tendency will increase in future, both as schools gain increasing autonomy, and as tertiary entry requirements become less rigid.

IMPLICATIONS

Several questions emerged from this initial study:

1. How stable is a student's individual learning style? If this task were repeated some weeks later, would students repeat these observations? Do students vary their style for different concepts within a discipline?
2. Can learning style (or cognitive strategy) be considered an intellectual skill? In discussing the relationship between memory structures and learning outcome, Gagne and White (1978) reviewed and defined intellectual skills as 'the concepts and rules that are defined as the memory structures that make possible rule application .... i.e. the learned capability of "knowing how"'. The definition of learning style as the student's perception of a task/topic fits within this general description.

3. If learning styles may be considered as intellectual skills, then how many can be distinguished — a single bipolar style with a continuum, or are they mutually exclusive, as Witkin (1977) has suggested? Or can there be more than one possessed by an individual as suggested by Thorsland and Novak (1974)?

4. Is the 'level of integration' different from learning styles? Marton (1975) has distinguished a hierarchy of levels of processing, Ausubel distinguished between rote and meaningful learning, Wertheimer described rote-memorizing and productive thinking. Or are these dichotomies different observations of learning styles in operation obtained by other methods of data collection?

**Validation by replication**

In sound scientific method the reproducibility of experimental observations is of the utmost importance. When dealing with human subjects (particulary tertiary students) this is not easy. I considered asking these students to repeat the Immunity task some weeks later, but rejected it for two reasons:

1) it could damage my relationship with them, and the enthusiasm with which they had participated in these studies,

2) even if they were willing, because of this first experience it would no longer be an unfamiliar task.
Nor was it appropriate to find another, similar group of students, for the main point of repeating these observations was to determine individual consistency.

One of the problems in the task interviews, B.9 the Graph problem, had been designed as visual material both for introducing questions about the future (Chapter 7) and in addition as a second descriptive task exploring learning styles. This Graph task could be considered a similar visual-verbal (oral) translation task. I have analysed students' interpretations of this graph into categories of learning style and level (8.3) and then compared these two similar tasks for individual consistency in 8.4.

8.3 THE SECOND DESCRIPTIVE TASK — THE 'GRAPH' TASK.

The final task in the interviews was a problem of graphical interpretation.

Development of the task

I prepared a histogram showing the dates of several important inventions associated with communication over long distances, and the time taken between discovery and wide application. (The original graph is reproduced in reduced form in Appendix VII). I chose this theme for two reasons. Firstly, 'language' is one of the great human characteristics, and therefore related to Human Biology. Secondly, several major inventions associated with language transmission show the dramatic exponential application of technology on both axes of the graphs, i.e. the time between inventions and the time before application. I introduced the task in the following way, for all students:
'Here is a graph showing the rate of technological change, associated with sending our language a long distance. The date of invention is on the horizontal axis, and on the vertical axis I've marked the number of years it took from the date of invention to the time of wide application. So in the 18th century, it took 150 years* from when the typewriter was first invented, to when it was widely available.

In 1962* the first satellite was launched which successfully had beams bounced back to earth, and three years later the commercial Early Bird satellite communications network was in orbit.

Would you tell me what you see in the graph?

(to a few students who were not clear on what was intended in this question, I rephrased the question: 'What does the graph tell you?')

(* pointed on graph)

(ORIGINAL GRAPH MEASURED 40 CM. X 20 CM.)
RESULTS

After inspecting random protocols, three different ways that students described the graph were identified. These were 1) those who analysed the graph in a single, vertical dimension, 2) those who analysed the graph in two dimensions, vertical and horizontal, 3) those who saw the graph as a (non-existent) Curve, or described a 'trend' in the graph.

Within each of these groups occurred students who actively explained why the graph was so. The two main reasons given were technological, or due to the intrinsic problem of communications itself. In my analysis these two reasons were grouped separately. Students who gave these added explanations were classed as showing a 'high' level of integration. Students who described the graph, without giving any reason or further explanation were classed as showing 'low' level of integration. (Note that in my introduction to the Graph task I did not specifically ask for an explanation).

The following examples were students' complete answers to this task.

Group 1. One-dimension. These students described the Graph in a vertical dimension only.

(a) Low level of integration.
'The discoveries are coming into circulation more quickly' (no. 36)

(b) High level of integration: (i) technological explanation
'The world's become more technological, its easier to persuade people more quickly. The typewriter took about 160 years and the silicon chip about three years — the market has progressed and now there's very little time before application.' (no. 5)

(ii) communications explanation
'As the rate of communications has increased, the rate people know about things has increased, and so it comes into use much quicker. The typewriter took years to spread. The silicon chip can be spread by telephone or satellite. Also there's possibly more need for the chips today. In the 1700's not many people could read or write, so there was not much demand.' (no. 52)
Two students classed as high level gave extremely detailed explanations, but within a vertical dimension description only. I emphasize this because such an instance weakens the single 'surface-deep' or 'rote-meaningful' dichotomies of Marton and Ausubel respectively.

'Well, the typewriter I suppose was developed for rapid communication of words on to paper and I think it was not widely distributed for a long period of time because there was no need for it — at the time there was not railways on that sort of thing, not going to have inter-country communications at a very quick rate and certainly not round the world. Think it has developed a lot in business — sort of trans-world business did not develop until after the industrial revolution so then there was more need for a typewriter to become more wide-spread. The telephone — it shows it was a difficult invention so to speak, they were not able to make it until they knew about electricity and translating it into a diaphragm and into words; but the communication at this time — the industrial revolution is under way, and communication was becoming more necessary and fashionable as well and I think the telephone helped to change in itself — there was a need for it but also by means of a telephone you could have conversations over long distances. The battery, well that again was invented when they knew how to store electricity and it took a few years before they put it into practice because (I think when it was first discovered they did not have radios and things like that?). TV was another communication device, I think it took a long time to be developed, not because it was used for communication over long distances, for they could use radio, but the cost of it; for the ordinary person to have a TV set before it became mass-manufactured and produced efficiently — the 1st ones were just small screens etc. The transistor battery was rapidly utilized because it could meet the needs for things like radio, torches easily. Satellites were better than telephones — faster communication and better at sending messages across the world and countries with bigger needs for communications — well, countries which could afford it sent all these up and they could bounce signals around. The silicon chip — that is so useful that it became widely accepted. It did not take them long to make factories which could mass-produce them — we find all sorts of applications for them — computers, transistors and of course the pocket calculator.' (no. 10)

Group 2 described both the vertical and horizontal dimensions of the Graph.

(a) Low level of integration:

'The discoveries are becoming more frequent, and as time progresses, the time taken to be accepted is becoming much shorter'. (no. 2)
(b) High level of integration: (i) technological:

'It shows how people were not used to technological invention when one was introduced, but as the amount of technology increases the inventions are becoming more rapidly used and the time between them is decreasing'. (no. 15)

Group 3 interpreted the Graph as a curve or a trend.

(a) Low level of integration:

'It seems to be exponential — if you draw a line (student indicated linking the tops of the bars), its taking less time'. (no. 32)

(b) High level of integration: (i) technological

'Technology, rather than pure science, is becoming increasingly efficient as it is being used. I cannot see the curve coming down much more, due to the social consequences'. (no. 9)

(ii) communications

'It's the original reason it took so long, you were not actually making contact with people, but with TV etc., today you are, so people notice it. There's a general exponential curve'. (no. 14)

I have included many examples to illustrate my analysis clearly.

Using this scheme of analysis, the following results were obtained, showing the distribution of both students combined (groups recorded within brackets thus (HB + NS))

Table III

<table>
<thead>
<tr>
<th>Level of integration</th>
<th>1 dimension (vertical)</th>
<th>2 dimension (vert. + horiz)</th>
<th>Curve</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low level:</td>
<td>(2 + 1) 3</td>
<td>(6 + 3) 9</td>
<td>(4 + 2) 6</td>
<td>18</td>
<td>35%</td>
</tr>
<tr>
<td>High level:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) technology</td>
<td>(8 + 5) 13</td>
<td>(2 + 2) 4</td>
<td>(5 + 0) 5</td>
<td>22</td>
<td>65%</td>
</tr>
<tr>
<td>(ii) communications</td>
<td>(3 + 7) 10</td>
<td>-</td>
<td>(2 + 0) 2</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>26</td>
<td>13</td>
<td>13</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>50%</td>
<td>25%</td>
<td>25%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table III shows that:

1. Half the students analysed the graph in a single, vertical dimension, one quarter analysed in two dimensions, vertical and horizontal. One quarter discussed the graph by mentally linking the histogram bars together, forming a curve, or trend.
2. When answers were inspected for those who gave explanations for why the graph looked like it did, two-thirds of students gave an explanation. I have identified two categories of explanations, those who referred to 'technology' and those who related the graph to the problem of communications: 'it's all built into itself'. Both kinds of explanation were classed as showing high level of integration for this task.
   One third of students gave no explanation and were classed as having low level of integration for this task. It is possible that some students classed as 'low' did not consider the task required any explanation.

8.4 CONSISTENCY OF LEARNING STYLES FOR TWO SIMILAR TASKS.

As outlined in 8.1 the serialist/holist categories of learning style, used in the Immunity task analysis were not continued, but were replaced for the final comparison with an analytic/holist dichotomy (with versatile students those who showed criteria of both these styles.)

The way students described this graph (8.3) and the way they had earlier described the diagram of Immunity (8.2), were two similar tasks, (one visual-oral, the second visual-verbal). Students' individual styles for these two tasks were compared to determine the degree of consistency.
For the purposes of comparison the following key points were used:

1. **Consistency.**
   (a) The breaking down of the Graph into its components, either 1 or 2 dimensions) and the breaking down of the 'Immunity' diagram into clear columns were considered consistent, analytical style.
   (b) The identification of a curve in the Graph and seeing the diagram as a whole were considered consistent, holist style.

2. **Versatility.**
   Students who had shown criteria of both styles in the Immunity task, were divided between the three groups, (vertical, 2 dimensions, curve) in the Graph task.

3. **Inconsistency.**
   Students who saw the Immunity diagram as a whole, but who saw the Graph in a single vertical dimension, or alternatively, those who saw the diagram as columns but who saw the Graph as a curve, were both considered to be inconsistent in their individual style used for these two tasks. (An alternative view is that they showed extreme versatility between tasks).

Using this analysis the two groups of students were distributed as is shown in Table IV.

<table>
<thead>
<tr>
<th>Style</th>
<th>HB</th>
<th>NS</th>
<th>Total</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Consistent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) A</td>
<td>11</td>
<td>10</td>
<td>24</td>
<td>50%</td>
</tr>
<tr>
<td>(b) H</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2. Versatile (Immunity)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(a) Curve</td>
<td>5</td>
<td>-</td>
<td>8</td>
<td>42%</td>
</tr>
<tr>
<td>(b) 2 dimensions</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>(c) 1 dimension</td>
<td>5</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>3. Inconsistent</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>8%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>29</td>
<td>19</td>
<td>48</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table IV DISTRIBUTION OF STUDENTS INTO CONSISTENCY OF LEARNING STYLES BETWEEN TWO TASKS
Table IV shows that:

1. Half the students (50%) maintained a singular style (either analytic or holist) which was considered very similar for these two tasks.

2. The twenty versatile students in the Immunity task were approximately evenly divided between the three categories of the Graph task, i.e. (a) as a curve (holist style), (b) in two dimensions (analytic style) and (c) in one vertical dimension (analytic style).

A possible complication in this Graph task was the mathematical background of these students. The majority of students have passed Maths at O-level. I did not investigate the amount of graphical representation in school syllabuses.

3. According to the criteria used in this comparative analysis, four students (8%) changed their style between these two tasks, and were considered inconsistent in their learning style for these two tasks. (These are circled in the overall Table VII, section 8.8)

4. In the HB group, no difference between the sexes in consistency of learning style was observed. Due to the unequal sex ratio in the NS group, no comment can be made.

8.5 COMPARISON OF LEVELS OF INTEGRATION FOR TWO SIMILAR TASKS

As has been described in 8.2 and 8.3, many students offered additional interpretations or explanations in these two tasks. Table VII, in section 8.8 shows these observations for the students individually. Using the inclusion of additional relevant knowledge or further explanation as the criterion to discriminate 'high' levels of integration, these students were grouped, as in Table V.
Table V
FREQUENCY OF STUDENTS SHOWING HIGH LEVEL OF INTEGRATION IN TWO TASKS

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>HB</th>
<th>NS</th>
<th>TOTAL</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Immunity task</td>
<td>48</td>
<td>13</td>
<td>8</td>
<td>21</td>
<td>44%</td>
</tr>
<tr>
<td>2. Graph task</td>
<td>52</td>
<td>20</td>
<td>14</td>
<td>34</td>
<td>65%</td>
</tr>
</tbody>
</table>

Further, when individual students' answers for the two tasks were compared, it was found that only four of the 20 students categorized as 'high' for the Immunity task were not also included in the larger population categorized as 'high' for the Graph task.

These observations further suggested that it is meaningful to distinguish between levels of integration, and learning styles.

The different results seen for these two tasks of the frequency of levels (Table V) can only be speculated about. It may be associated with familiarity of the topic or content of the problem. In the Graph task, the topic, the rate of technological change in society, was familiar to students and 65% gave detailed explanations of why the Graph looked as it did. In contrast, the topic of Immunity was unfamiliar to all but four students (excluding any informal reading, which I could not ascertain). These students are asterisked in Table VII, 8.8. Further studies into the relationship between learning style and level of integration may clarify this point. The possible relationship between level of integration and content of task is in line with Ausubel's (1968) belief that problem-solving is not a generalized trait, but varies on the basis of interest, experience and aptitude in particular fields.

It should be pointed out that observations on levels of integration cannot be made using nonsense tasks, or intellectual Games (as in Bruner 1956 and some of Pask's methods (1972), as such tasks have no relationship to any meaningful existing knowledge.
8.6 THE HYPOTHESIS-TESTING TASK: THE ROCK PROBLEM

The Rock problem, described in (6.2), as one of the problems testing students' understanding of the concept of 'life' had been given to students in the individual task interviews of Stage 2, and students' answers had been transcribed verbatim. In this problem three sub-questions had been posed, and these required students to formulate three hypotheses to test, to find a solution.

This problem therefore was suitable to examine also from the aspect of learning style to a task, which was quite a different skill from the two visual-verbal translation tasks already described. For this analysis of learning style I have identified this problem as the hypothesis-testing task.

Analysis of observations.

The Rock problem required students to 'sort out' their reasoning logically in order to cover all three possibilities (alive, dead or non-living). Examination of students' protocols showed that for some students this was an absolutely straightforward exercise — they retained the question formulating hypotheses and described appropriate tests they could use:

'To tell if it is alive I'd measure CO$_2$ and O$_2$ changes in a closed environment. If these were both negative, it's either dead or non-living. To tell if it's dead I'd do a dissection and examine a piece microscopically to see if it's made of cells. Non-living would have no cells' (no. 4)

These students showed high analytic style for this task.

Several students showed a similar degree of analysis, but did not give a complete answer. However they were aware of this and pointed it out:

'Well if it has been alive it would contain carbon, because all living things are organic, so test for carbon. If it is alive, either it will breathe in O$_2$ and give off CO$_2$ if aerobic or if its anaerobic it'll produce waste products like alcohol and CO$_2$. I actually found this question very difficult, about life on Mars (i.e. A.6). If it reproduced, or had structures indicating reproduction, if it excreted, if it grows. I can't think of any more. I don't know how I'd distinguish non-living from dead'. (no. 39)
In contrast to the examples given above, some students did not seem to retain the question, and described tests without clearly formulating hypotheses, making predictions, or drawing conclusions.

'Cut it open and see inside, but I don't know what. Go back a few days later and see if had shrivelled up, changed colour, or grown anything. Put it in water and see if it had any effect — absorbed water, gave off secretions or gases.' (no. 13)

Some gave a very descriptive account:

'If I was really curious I might see if I could break it — it sounds a pretty barbaric thing to do if it is alive — and if it broke and if it wasn't hard all the way through I'd think that quite strange, that it wasn't hard all the way through. To me that would mean that maybe this is alive, you know, or was alive. After that I really don't know — it all depends on what happened when I broke it open.' (no. 23)

Several students mentioned looking for environmental evidence, i.e. not a direct component of the 'rock' but some evidence of its presence:

'....look for a trail or traces of how it got there...' (no. 49)

'....look at the environment, see if there's more of them...' (no. 40)

'....see if any lettuce is eaten, or any excretory products'. (no. 12)

Others referred to the characteristics of life:

'....basically you'd look for the seven characteristics of life...' (no. 25)

These distinctly different approaches to solving this problem seemed closely related to Witkin's (1977) field-dependence dichotomy, with its 'hypothesis-testing' vs. 'spectator-approach'.

For this task, the useful criteria for defining these two learning styles were:

**Analytical:**

- retained the three questions uppermost,
- made hypotheses and then described appropriate tests, in three discrete steps,
- made predictions and drew conclusions from these tests,
- saw the object in isolation from its environment.
Holist:

gave a more descriptive outline, often talking around living/non-living,
looked for characteristics,
focused on tests to use, without drawing conclusions,
lost track of the three parts of the problem.

Using these criteria I attempted to categorize all students into style.
I did not find it possible to analyse into levels of integration for this task.

RESULTS. The following results were obtained:

1. Students using holist style were difficult to see as a spectrum, and were classed into a single group only.
2. Students using a purely analytical approach showed a continuous variation from low, through moderate (i.e. incomplete analysis but were aware of this), to high degrees of analysis.
3. Some students showed characteristics of both styles.

Several qualifications should be made about drawing such apparently clear-cut distinctions.

(a) The question was worded in a very analytical style, and this may have influenced students to answer in that style rather than a personally preferred style. Therefore a very high 'analytical' style and lower 'holist' or mixed style may have been cued.

(b) Students categorized as low in analytical style included very brief answers. In such very incomplete answers, where only one test may have been mentioned, students could be interpreted as either using low analytical or low holist style. This task did not permit indisputable distinction between these two possibilities:

'Touch — to see if it moved, or was soft or wet. All these would tell if it is alive. Cut it up and see what's inside, but I don't know what I'd expect.'
(I probed further after I was sure the answer was complete — what about non-living?)

'There would be no movement.'

(What about dead?)

'There would be no movement.' (no. 29)

With these qualifications the results of the two groups of students (HB and NS) were combined in Table VI.

<table>
<thead>
<tr>
<th></th>
<th>Analytic(A)</th>
<th>Holist(H)</th>
<th>Versatile (A+H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Couldn't do it</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>9</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>4</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>O</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

TOTAL (%) 33 (63%) 6 (12%) 9 (17%) 4 (8%)

<table>
<thead>
<tr>
<th></th>
<th>Q:O+</th>
<th>Q:O+</th>
<th>Q:O+</th>
<th>Q:O+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q:O+</td>
<td>21 Q; 12 O+</td>
<td>4 Q; 2 O+</td>
<td>4 Q; 5 O+</td>
<td>4 Q; 0 O+</td>
</tr>
<tr>
<td>(% of all Q:O+)</td>
<td>(64%:63%)</td>
<td>(12%:11%)</td>
<td>(12%:26%)</td>
<td>(12%:0%)</td>
</tr>
</tbody>
</table>

Table VI shows that, for this task, 63% of these students answered this problem with a purely analytic style, 12% showed no analytic style but explained it by using criteria which may relate to holist style, and 17% showed characteristics of both these styles in their explanations.

Only the analytic students' answers were further sub-divided into degrees of analysis and of these thirty-three students, eight (22% of the total population) showed extremely high analysis.

No sex difference was observed in the analytic group overall.
Comparisons with familiar organisms.

Ten students referred to specific animals or plants in their explanations. The following extracts have been grouped into the style a student showed in this problem.

Analytical style:

'...ask an expert to classify it' (nos. 16, 22, 45)
'Most animals of that size are vaguely probable' (no. 49)
'... if it's solid it may have been alive once, e.g. coral' (no. 52)
'... if it's cold, it's either a stone or fungus' (no. 42)

Versatile:

'touch to tell texture, would tell if rock or fungus' (no. 25)
'look to see if shape resembles something else' (no. 17)
'look for something similar in books' (no. 41)

Holist style:

'chop it up and compare with other fungi I've chopped up before' (no. 47)

These results further illustrate that analytical students tended to formulate hypotheses and make predictions. Holist and versatile students made more comparisons with familiar examples. It is unwise to draw definite conclusions from this small set of observations.

Pask (1976) distinguished between simple and complex hypotheses. He stated that operation learners favour simple hypotheses and comprehension learners make complex hypotheses, but he did not say how he characterized these two levels of hypotheses. In this task is the hypothesis 'if it is alive' more complex than 'if it is a fungus'?

DISCUSSION

The observations in this task resembled some of Witkin's criteria determining field-dependence, field-independence (e.g. spectator vs. hypothesis-testing approach). One important difference, however, is that Witkin used his categories as mutually exclusive, stable characteristics of students, irrespective of the task.
The percentage distribution for this task differed from those of the first two tasks, with a higher percentage showing analytic style. The task itself was worded in an analytic way; the results suggest that either the style of the task itself influenced students' style of answer, or that learning style was not consistent across different tasks.

8.7 OTHER OBSERVATIONS RELATED TO LEARNING STYLES

Other, incomplete observations associated with learning style have been described in Stage 2. These were:

A.5 Fire Problem (Chap. 6.2)
Instances of highly original thought, (env.) (the 'environmental' category), and a high degree of analysis (A) (analysis of cellular respiration), have been tabulated, Table VII, 8.8.

B.3 Rock Problem (Chap. 6.2)
In addition to the overall analysis as a hypothesis-testing task, various comments ('ask an expert', 'compare with a known plant or animal', being aware of gaps in their answer, and looking for evidence in its surrounding environment) have been tabulated, in an abbreviated form.

A.3 Linear Time-Scales (Chap. 7.2)
Students who focused on the events, rather than marking off a scale first, classed as Poor linear-scalers, have been denoted with an 'X' in the appropriate column of Table VII, 8.8.

B.7, B.8 Mismatched Future Predictions (Chap. 7.5)
Students whose personal future predictions were mismatched to their earlier global future predictions have been denoted 'X' in Table VII. Those who specifically distinguished this point have been denoted '√' in the same column.

B.9 Examples Used to Illustrate Attitudes of Older Generation (Chap. 7.6)
Comparisons between their generation and the older generation's acceptance
of technological inventions or other examples have been identified in a separate column.

A few students who made specific comments on 'clear, ordered lectures', 'facts not uncertainties' have also been recorded.

8.8 CONSISTENCY OF LEARNING STYLES FOR SEVERAL BIOLOGICAL TASKS

Up to this point all analyses had been done on numerically coded protocols, with each set of observations done without reference to, or comparison with individual student's previous responses. In order to examine consistency of style, or related criteria, students' individual task responses were tabulated on a master table, Table VII, 8.8.

In attempting to summarize all these observations of the ways individual students approach these various tasks, I have retained the terms I used at each stage. Before tabulating the complete results for 52 students Table VII, I have briefly re-defined the symbols used for each of the three tasks. The other observations are abbreviated in a separate column. The two right-hand columns categorize individual student's overall learning style and level shown for these observations, summarized in Table VIII 8.9.

1. 'Immunity'

- circled observations indicate inconsistencies in style for the 4 students identified in 8.4.
- diagram described as discrete vertical columns, every step included.
- diagram outlined in an 'overview' way, linking top line and bottom line in introduction, making lateral comparisons of parallel points. Memory discussed as belonging to both T and B cells.
2. 'Graph'

1 dim. — student described graph as vertical bars of decreasing height.
2 dim. — both vertical height, and also horizontal time-spacing decreasing were identified.

curve — student described a 'curve' in the graph without mentioning any detail of dimensions above.

+ — high level of integration, given for why the graph looked like this.

+t — explanation used was due to 'technology'.
+c — explanation used was in terms of 'communications'.

3. 'Rock Problem'

A — analytical skill. Student retained the 3 parts of the question as hypotheses, and described tests which would be appropriate to make predictions/clear conclusions about hypotheses.

(high A students completely accounted for all 3 parts of Q.)
(mod. A students did not account for all 3 some were aware of their omissions)
(low A students covered one or two parts of Q only.)

H — student described tests first and did not relate to any specific part of the Q. No conclusions drawn — but would 'depend' on what happened in the tests/observations.

A+H — elements of both these groups.

□ — inconsistency of style of this task compared with other two tasks.
<table>
<thead>
<tr>
<th>Code</th>
<th>Sex</th>
<th>Immunity</th>
<th>Graph Task</th>
<th>Rock Problem</th>
<th>Fire</th>
<th>Mismatch</th>
<th>Poor Linear Scale</th>
<th>Example in age</th>
<th>Overall</th>
<th>Style</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O</td>
<td>S</td>
<td>2 dim</td>
<td>mod. A, aware gaps</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>O</td>
<td>S</td>
<td>2 dim</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>O</td>
<td>-</td>
<td>curve +t</td>
<td>A + H</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>O+</td>
<td>S</td>
<td>1 dim +t</td>
<td>high A</td>
<td></td>
<td></td>
<td></td>
<td>(lectures should be clear)</td>
<td>A</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>O+</td>
<td>S</td>
<td>1 dim +t</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td></td>
<td>(likes ordered lectures)</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>O+</td>
<td>S+H + (gap)</td>
<td>2 dim</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>O+</td>
<td>H</td>
<td>2 dim +t</td>
<td>high A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>O+</td>
<td>S</td>
<td>1 dim +c</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>A+H</td>
</tr>
<tr>
<td>9</td>
<td>O+</td>
<td>S+H +</td>
<td>curve +t</td>
<td>high A + H, looks moribund</td>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>O+</td>
<td>S+H +</td>
<td>1 dim +t</td>
<td>high A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>O</td>
<td>S+H</td>
<td>1 dim</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>O</td>
<td>H (gap)</td>
<td>curve</td>
<td>H, look in environment</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>O</td>
<td>S</td>
<td>curve +c</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>O</td>
<td>S</td>
<td>2 dim +t</td>
<td>A + H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>O+</td>
<td>S+H</td>
<td>1 dim +t</td>
<td>low A, ask expert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>A+H</td>
</tr>
<tr>
<td>16</td>
<td>O+</td>
<td>S</td>
<td>2 dim</td>
<td>low A, ask expert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>O+</td>
<td>S+H +</td>
<td>curve +t</td>
<td>A + H, compare familiar</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>O+</td>
<td>S+H +</td>
<td>1 dim +t</td>
<td>A + H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>O+</td>
<td>S+H +</td>
<td>1 dim +c</td>
<td>A + H, aware gaps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>O+</td>
<td>S</td>
<td>2 dim</td>
<td>mod. A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>O</td>
<td>S+H</td>
<td>2 dim</td>
<td>mod. A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>O</td>
<td>S</td>
<td>1 dim +t</td>
<td>A, ask expert (couldn't do it) (likes facts)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>O+</td>
<td>S+H +</td>
<td>curve +t</td>
<td>A + H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>O+</td>
<td>S</td>
<td>1 dim +t</td>
<td>high A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>O+</td>
<td>S+H</td>
<td>curve +c</td>
<td>H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>O+</td>
<td>H (gap)</td>
<td>curve +t</td>
<td>low A, aware gaps</td>
<td>env.</td>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>O+</td>
<td>-</td>
<td>curve</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>O</td>
<td>S+H</td>
<td>1 dim +c</td>
<td>A + H</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>O</td>
<td>-</td>
<td>1 dim</td>
<td>low A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>O</td>
<td>S</td>
<td>1 dim +t</td>
<td>A (couldn't do it)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>O</td>
<td>S+H</td>
<td>1 dim +t</td>
<td>A (couldn't do it)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td>high</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>O</td>
<td>S+H</td>
<td>curve</td>
<td>high A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table VII

<table>
<thead>
<tr>
<th>Code No</th>
<th>Sex</th>
<th>Immunity Task</th>
<th>Graph Task</th>
<th>Rock Problem</th>
<th>Fire</th>
<th>Mismatch</th>
<th>Poor Linear Scale</th>
<th>Examples in age</th>
<th>Overall Style Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>♀</td>
<td>S+H</td>
<td>1 dim +t</td>
<td>high A</td>
<td>X</td>
<td></td>
<td>A+H</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>♀</td>
<td>S</td>
<td>2 dim +t</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>♀</td>
<td>S +</td>
<td>1 dim +c</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>high</td>
</tr>
<tr>
<td>36</td>
<td>♀</td>
<td>S</td>
<td>1 dim</td>
<td>low A</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>♀</td>
<td>S +</td>
<td>1 dim +c</td>
<td>high A</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>high</td>
</tr>
<tr>
<td>38</td>
<td>♀</td>
<td>S+H</td>
<td>1 dim +c</td>
<td>low A</td>
<td></td>
<td>X</td>
<td>tractors</td>
<td>A+H</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>♀</td>
<td>S+H</td>
<td>1 dim +t</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>♀</td>
<td>H</td>
<td>curve</td>
<td>H. look in env. may be rock,</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>♀</td>
<td>S+H</td>
<td>1 dim +c</td>
<td>A + H. look in books</td>
<td></td>
<td></td>
<td>Shah</td>
<td>A+H</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>♀</td>
<td>S</td>
<td>curve</td>
<td>low A</td>
<td></td>
<td>X</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>♀</td>
<td>S</td>
<td>2 dim</td>
<td>mod. A, aware gaps,</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>♀</td>
<td>S+H *(gap)</td>
<td>2 dim</td>
<td>(couldn't do it)</td>
<td></td>
<td>X</td>
<td>A</td>
<td></td>
<td>A+H</td>
</tr>
<tr>
<td>45</td>
<td>♀</td>
<td>S</td>
<td>1 dim +t</td>
<td>mod. A, ask experts</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>♀</td>
<td>S</td>
<td>1 dim +t</td>
<td>high A</td>
<td></td>
<td></td>
<td>env A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>♀</td>
<td>S+H +</td>
<td>2 dim +t</td>
<td>H, compare with similar</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>A+H</td>
</tr>
<tr>
<td>48</td>
<td>♀</td>
<td>S+H</td>
<td>2 dim</td>
<td>mod. A</td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td>high</td>
</tr>
<tr>
<td>49</td>
<td>♀</td>
<td>S+H +</td>
<td>1 dim +t</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>env</td>
<td></td>
<td>A+H</td>
</tr>
<tr>
<td>50</td>
<td>♀</td>
<td>S</td>
<td>1 dim +c</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>/</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>♀</td>
<td>S +</td>
<td>1 dim +c</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>man on noon</td>
</tr>
<tr>
<td>52</td>
<td>♀</td>
<td>-</td>
<td>1 dim +c</td>
<td>mod. A, aware gaps</td>
<td></td>
<td></td>
<td>env.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total = 33 ♀ 19 ♂ = 52 students (HB and NS combined)
The frequency of overall learning styles and levels of integration is discussed in 8.9. Table VII shows that most of the incomplete observations collected on other problems (the fire problem, time-scales, mismatched predictions and examples used in relation to older generation) cannot be clearly associated with a specific learning style or level of integration.

8.9 OVERALL ANALYSIS OF LEARNING STYLES AND LEVELS OF INTEGRATION SHOWN BY STUDENTS.

I have identified three groups of students, those who have consistently used only one style (either analytic or holist) throughout these tasks, and those who have used a combination of these two styles (versatile). Those students who were inconsistent between the two descriptive tasks have also been classed as versatile.

All students who gave further explanations in the first two tasks, denoted by two '+' in the first two columns of Table VII have been placed in a high level of integration category, within their overall style. The following table, Table VIII summarizes the distribution of students.

Table VIII OVERALL DISTRIBUTION OF 52 STUDENTS INTO LEARNING STYLE FOR SEVERAL TASKS.

<table>
<thead>
<tr>
<th>Level of Integration</th>
<th>Analytic Style (A)</th>
<th>Holist Style (H)</th>
<th>Versatile (A+H)</th>
<th>Total %</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QT</td>
<td>22,30,31,35,37</td>
<td>18,47,49,51</td>
<td>16</td>
<td>31%</td>
</tr>
<tr>
<td>Q+</td>
<td>4,24,</td>
<td>7,9,10,17,23</td>
<td>(27%Q:37%Q+)</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QT</td>
<td>1,2,8,29,34,36,39,43,45,46.</td>
<td>3,11,13,14,21,28,32,33,38,41,42,44,48</td>
<td>36</td>
<td>69% (73%Q:63%Q+)</td>
</tr>
<tr>
<td>Q+</td>
<td>5,16,20,50,52.</td>
<td>26,27,40</td>
<td>6,15,19,25</td>
<td></td>
</tr>
<tr>
<td>TOTAL Q</td>
<td>15 (45% of all Q)</td>
<td>1 (3%)</td>
<td>17 (52% of all Q)</td>
<td>33</td>
</tr>
<tr>
<td>O+</td>
<td>7 (37% of all O+)</td>
<td>3 (16%)</td>
<td>9 (47% of all O+)</td>
<td>19</td>
</tr>
<tr>
<td>TOTAL</td>
<td>22</td>
<td>4</td>
<td>26</td>
<td>52</td>
</tr>
<tr>
<td>%</td>
<td>42%</td>
<td>8%</td>
<td>50%</td>
<td></td>
</tr>
</tbody>
</table>
Table VIII shows that of these fifty-two students, when all observations have been taken into account, 42% maintained a single style which I have called an analytic style, 8% of students maintained a single style called a holist style, and 50% showed characteristics of both of these styles.

The only difference in the sex ratio for any one style was in the holist style, where 16% of all male students in the group, but only 3% of all female students used this style for all tasks. These were very low numbers to draw definite conclusions.

8.10 DISCUSSION

From these observations, using several tasks, with the same Biology group, I have found it meaningful to consider style as distinct from level of integration in my analyses. No one test adequately showed overall style and level for all students.

The results show two large groups of students — one group using only analytic style, the other using a mixture of both analytic and holist styles. The third group of students, those using only holist style was a very small group in this population of Biology students, for the tasks of this project. These observations, using real biological tasks, suggest that Bruner's 'intuitive' group (the reciprocal of his analytic group) may be partly due to his 'games' methods of data collection.

The results also show that the nature of the particular task can influence the responding student's own style. A higher percentage used an analytic style for the hypothesis-testing task, than had been observed for the two descriptive tasks. This is in agreement with Witkin's (1977) findings on field-dependence, and Rothkopf and Bisbicos' (1967) finding on interjected questions of a reading-comprehension task.

Since versatile students have shown as high an analytical style as have pure analytic students, I do not consider that the continuum model
of a bi-polar dichotomy of one style, i.e.

```
analytic ←------------------------→ holist
```

is adequate. On this model, a student with both styles, (i.e. somewhere in the middle of the line) should have both styles to a weaker degree (50:50) than a student at either pole (100). This has not been observed, some students have shown both styles to a high degree, some both to a low degree and some students have shown only one. I believe that these observations are more adequately accounted for by the 'two independent styles' model, according to Thorsland and Novak's (1974) model:

```
analytic ↓
```

```
holist
```

In addition to varying on learning styles, these students also varied on the 'level of integration' they showed in different tasks. It was interesting to observe students attempting to make connections to, and explain, (often incorrectly), an unfamiliar task, the Immunity task. More students gave additional explanations, i.e. a high level of integration, in the familiar Graph task. All these students still showed different styles associated with high levels of integration. Some very detailed descriptions were given in a purely analytic style (i.e. step-wise). Moreover, students classed as versatile did not NECESSARILY give additional explanation which would classify them as high level. It is difficult to imagine how Marton would characterize these observations into his simple 'surface-deep' levels of processing dichotomy. On Marton's multiple criteria (1975) used to distinguish between these levels of processing, the most accurate representation of the two groups he seems to be identifying is shown by the arrow in the following diagram:
The observations described in this chapter suggest that learning styles are independent of each other and are not mutually exclusive. They further suggest that level of integration is independent of learning style and has a definite hierarchical categorization of 'low' and 'high'.

It may be more meaningful to consider a three-dimensional model, with the third vertical axis representing 'level':

Why is the holist style group so small? There are several points to raise:

1. The tertiary population participating in Stages 2 and 3 of this project has had a scientific secondary school background. Most examinations in science subjects have a detailed knowledge component. One could argue that only those students with a well-developed analytic style will be successful in such an exam. system and reach University; i.e. a selective process is operating, and style is innate. Alternatively one could argue that their education has taught the majority of these students to develop this style in preference to others, i.e. an adaptive process is operating, and style is learned.
It is impossible to distinguish between these two possibilities from the results described in this thesis — only longitudinal studies would do this. Of interest here are the field-dependence differences already present in very young (5 year old) children, described by Nebelkopf and Dreyers (1973).

2. Studies of a parallel population of non-scientific tertiary students (e.g. Arts), with appropriately designed task material, could well give a higher proportion of students using holist style, and lower proportion of analytic style. Studies of reading-comprehension tasks, and Dahlgren's economics problem-solving studies (1978) could fall into this category. Such a difference would still not resolve the innate-learned possibilities described in 1. above.

3. In retrospect, I regret I did not design a 'holist-orientated' task — to contrast with the hypothesis-testing task. Since learning style is obviously influenced, to some extent, by the nature of the particular task, such an additional task may have resulted in a larger proportion of students using this style for this extra task.

In this analysis it was possible to identify degrees of analytic style, low, moderate and high. This was not possible in the case of holist style, partly due to the low numbers, but also due to the absence of accepted, sensitive criteria used to evaluate this style.

For the students placed in the 'low' category it was in some instances rather arbitrary to type their sketchy answers into a particular style. These students may represent the 'below-average' individuals in this population, for in these studies I have included the entire first-year intake into these two courses.

4. The finding of some students who have shown only analytic style (or only holist style) for all these tasks, raises the interesting question of the long-term stability of a singular style. Are these students able to
use both styles by the end of their course? A longitudinal study would be most worthwhile, as such detailed data has been recorded at the entry to their courses.

5. It should be emphasized that analytic style, i.e. (students' perception of the components of a task) can be very highly developed and have associated with it high levels of integration. This is in contrast to Pask's 'operation' learning, and Ausubel's 'rote-learning', both of which are far more allied to Marton's 'surface-processing'. Both Ausubel and Novak (and, from the original Gestalt school, Wertheimer) discuss rote-, and meaningful-learning which is the desired outcome of learning. The relationship between learning styles, levels of integration and meaningful learning is further discussed in the next chapter.

8.11 SUMMARY

8.2 1. In an unfamiliar visual-verbal translation task, the Immunity task, 50% of the population of first-year HB and NS students used a purely analytic style, 8% used a holist style and 42% used a mixture of these two styles.

2. Just over one-half of the students (56%) actively tried to explain this topic by introducing new information into their answers; they were defined as showing 'high' levels of integration. Just under one-half (44%) did not go beyond the content of the task and were termed 'low' in level of integration.

3. Within the analytic group, a sex difference was observed, with nearly 60% of all female, but only 30% of all male students, using this style.

8.3 4. In a second, similar task, the Graph task, 50% of students showed an analytic style, 25% a purely holist style and 25% a mixture of styles.
8.4 5. When the students' results were individually compared for these two tasks, it was found that 50% of students maintained a singular style (either analytic or holist), which was consistent; 42% of students who showed versatility of style in the Immunity task, were distributed equally into the three groups analysed for the Graph task; and 8% of students changed their style between these two tasks.

8.5 6. The 'high' level of integration for the familiar Graph task was larger, and included all but four of the 'high' level students of the unfamiliar Immunity task. This suggests some consistency of 'level' in addition to style, but may relate to the content of the particular task.

8.6 7. A third task, the hypothesis-testing task (the Rock problem) showed that, in this task, 63% of students used a purely analytic style, 12% a purely holist style and 17% a mixture of styles.

8. Taking these observations overall, the percentage of female and male students showing a purely analytic style, was approximately equal. A trend of a higher proportion of male students using a purely holist style warrants further study.

8.9 9. Taking all observations of learning style into account for individual students, it was found that, for these tertiary biology students, 42% used a singular analytic style and have not shown any holist style whatsoever, conversely 8% have explained all tasks in a purely holist style, and 50% have shown varying ability to use both styles in different tasks, or for the same task.
CHAPTER 9

RELATIONSHIP BETWEEN LEARNING STYLE AND CONCEPT UNDERSTANDING

In Chapter 8 I identified consistent learning styles for the majority of the fifty-two first-year students of the Human Biology Department, using a variety of biological tasks. Learning styles were identified as analytic, holist or versatile.

In Chapter 5, for these same students, I analysed their understanding of one of the fundamentally important biological concepts, that of natural selection, using a series of problem-solving tasks. In this analysis (5.4) I grouped students into 'sound', 'partial' and 'poor' understanding. A concepts identification question (5.5) confirmed that only those students classed into 'sound' understanding could identify the correct concepts underlying these problems. 'Poor' students identified the 'content' of the problem, or other misconceptions.

If learning style is to have more than 'academic curiosity' and is significant in contributing to meaningful learning, then it is important to find evidence to support this hypothesis. Using the instance of 'natural selection' as an instance of meaningful learning, I have explored the relationship between meaningful learning and learning style observed for these students, in this Chapter.

9.1 IDENTIFICATION OF STUDENTS WITH SOUND UNDERSTANDING OF NATURAL SELECTION

In Chapter 5 Table II showed that only eight students (15%) were consistently able to identify and correctly apply the concept of natural selection in unfamiliar problems. A further nine (17%) showed partial understanding while the majority of students tested, 68% showed very poor understanding.
I have reproduced Table VIII, Chap. 8.9, summarizing individual student's learning style and level of integration. The eight students with sound understanding of the concept of natural selection have been circled. Those with partial understanding have been underlined.

Table I  OVERALL DISTRIBUTION OF STUDENTS' LEARNING STYLES, IDENTIFYING THOSE UNDERSTANDING THE CONCEPT OF NATURAL SELECTION.

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>LEARNING STYLE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analytic (A)</td>
</tr>
<tr>
<td>High</td>
<td>22,30,31,35,37,</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>1,2,8,29,34,36,</td>
</tr>
<tr>
<td></td>
<td>39,43,45,65</td>
</tr>
<tr>
<td></td>
<td>5,16,20,50,52,</td>
</tr>
</tbody>
</table>

Table I shows that four of these eight students were classed as versatile students (i.e. able to use both styles), with a high level of integration. Two students were classed as versatile with a low level of integration, one student was classed as analytic with a low level, and the eighth student was classed as holist in learning style with a low level of integration.

The nine students with partial understanding were distributed more widely on learning styles and levels of integration, three being classed as versatile with a low level, one versatile high level, one as analytic with high level, and four as analytic learning style with a low level of integration.
9.2 DISCUSSION OF THE RELATIONSHIP OF CONCEPTUAL LEARNING TO THE STRUCTURE OF KNOWLEDGE

These two sets of observations were obtained from completely separate problems and tasks, both written and oral, only the students being the same in both sets of observations.

The results shown in Table I highlight the importance of developing both learning styles for Biology students. Biology is a difficult subject, its difficulty not being due to abstractness (as is Mathematics), but due to its complexity. These results suggest that the complex interrelationships which occur in Biology (of which the concept of natural selection is an example) cannot be fully grasped if only an analytic style, (i.e. the traditional scientific analytic method) is developed, but in addition they require a holist style.

Meaningful learning, as defined by Ausubel, mainly belongs to those versatile students who actively attempt to integrate and relate new knowledge to their existing understanding, which I have called a 'high' level of integration. These results support the hierarchical nature of 'high' and 'low' levels of integration, described in 8.1, as distinct processes from learning styles.

In Chapter 2.9 I put forward an operational definition of a concept — i.e. what a concept does to link individual entities together into a category. In 1.2 I reviewed the two models of the conceptual hierarchy of knowledge, put forward by Ausubel (1968) and Gagne (1977). Both of these workers described an organization of knowledge based on a 'pyramids-within-pyramids' model. Novak (1977) described the difference in the sequence of learning recommended by these two workers: Ausubel starting with the most super-ordinate concept and progressing down to the lowest level concepts, while Gagne recommended the reverse, i.e. starting with the lowest concept and working up to the more general, super-ordinate concepts.

This difference may be significant if one is moving between the most
simple, concrete concepts ↔ very complex, abstract concepts within the
same learning sequence. However much conceptual learning (especially at
tertiary level) involves relationships between complex concepts. This
highlights a weakness in this structural model, for it seems to represent
a rather static structure, in an **absolute** framework of super-and sub-ordinate
class hierarchy.

However I do not believe that knowledge can be interpreted in such a
static model, in an absolute framework — the three-dimensional 'structure'
is **dynamic**, and the concepts should be seen in a **relative** framework. For
example if one considers the concept map of evolution (Appendix II),
(which for the purposes of my study can be adequately drawn in two-dimensions)
then clearly, the concept 'evolution' is a super-ordinate concept to 'life';
**BUT** if 'life' is the focus of students' interest, then the related concepts,
including evolution, (and possibly others from the three-dimensional
structure) will be sub-ordinate to it. In other words the 'structure' is
fluid, and related, higher order concepts need to be organized depending
on the particular point of focus.

Another biological example may clarify this dynamic relative component
of conceptual learning. Traditionally the various specialized systems of
the body — e.g. digestive, respiratory, excretory, are taught as separate
'absolute' topics, according to their individual function. In conceptual
learning these systems can be functionally linked, in a variety of ways:
e.g. (a) using the concept of the internal-external environment interface,
four specialized regions (all sharing the additional characteristics of a
**high surface-area: volume ratio**, and a **rich capillary bed**) can be
conceptually, or functionally linked. Each of these regions can be
further linked to the respiration equation, as is shown in the following
diagram:
e.g. (b) using the concept of the active transport of substances across a cell membrane, a different grouping of regions results:

(i) **active uptake of glucose**
   - gut
   - kidney

(ii) **active transport of Na⁺**
   - kidney
   - neurone

i.e., conceptual learning involves the **functional** relationships which are not fixed in an absolute and static pattern, as in traditional cell specialization. It is here, in this dynamic re-organization of existing concepts that misconceptions arise, if new concepts are integrated with incorrect, existing ones. Ausubel has not clearly displayed the relativity of super-ordinate concepts, for he has used an 'absolute' framework in his model of the conceptual structure of knowledge.

If this relative view of a dynamic structure is accepted for complex, higher-order concepts, then Ausubel's and Gagne's models may not be as completely opposite as Novak (1977) has suggested. I believe this dynamic component of conceptual teaching and learning must be clearly emphasized if a two-dimensional structural model is used to describe the relationship in conceptual learning.

Novak (1977) has pointed out that in presenting material in a logical (i.e. traditional) order, 'the integration of ideas and concepts is left to the individual student'. He believed each individual forms a framework of concepts in idiosyncratic ways, and this uniqueness is comprised of the cognitive, affective and emotional experiences of learning. I believe the
observations described in this project have demonstrated that it is not enough to learn 'knowledge', without learning how to use the knowledge which is our cultural heritage.

Problem-solving has been an illuminating technique in demonstrating students' perceptions of basic biological concepts. It has also shown its value in exploring students' learning styles. I believe that problem-solving is also an important technique in teaching and can help students in conceptual learning as well as give them experience of variations of learning styles.

The only method of the short-term effective teaching and meaningful learning that has been developed in education is by various methods of the assessment of achievement. Some observations of these students as to the role of learning style in different forms of assessment are the subject of the next Chapter.

9.3 SUMMARY

Using the understanding of the concept of natural selection as an instance of meaningful learning, it was found that four out of the eight students with sound understanding belonged to the versatile learning-style group of students, showing a high level of integration.
CHAPTER 10 THE ROLE OF LEARNING STYLE IN SOME FORMS OF ASSESSMENT

The traditional form of examination question has been the essay. Several major criticisms have been levelled at examination by essay alone:

a. ambiguity, or a lack of definition as to what is required in a good answer,
b. subjective marker unreliability between different answers,
c. the time taken to mark essays, where a large number of students are involved,
d. poor syllabus coverage.

The most significant attempt to overcome these problems has been the development of 'objective testing' (described in Nedelsky 1965), usually as a single choice from multiple alternative answers. Since only one answer is theoretically correct, this method improves marking reliability to the point that a computer can process student responses accurately, objectively and quickly. Moreover, a much broader range of the syllabus (albeit at less complex level) can be covered in the time limit using this method. Thus both b, c, and d, above are alleviated, but what about a? The central problem of precise definition may even be accentuated, since now not only the question but also the wording of all alternative answers must be unambiguous (Hoffman 1964).

Between these two extremes of essay and multiple-choice question (MCQ) lies the short open-response (OR), which has been the main method of problem-presentation used in these studies.

As has been documented in 2.7, the majority (75%) of the students participating in Stages 2 and 3 have had experience with biological MCQ's prior to University entry. University Departments are increasingly using a variety of types of questions, in addition to the traditional essay type, in formal examinations. Accurate assessment is dependent on the sensitivity
and validity of the techniques of measurement of assessment. I was interested in including observations relating to different methods of assessment involving problem-solving in this project. Two sets of observations were made on these students:

1. Students were individually asked about problem-containing MCQ's i.e. set at Bloom's higher levels of analysis, synthesis and evaluation,

2. Following a course exam, they were asked about reasons determining their choice of essay. In this Chapter I have analysed the role of learning style in these two aspects of examination questions.

10.1 THE USE OF MULTIPLE-CHOICE QUESTIONS IN PROBLEM-SOLVING

For the first question in the task interviews I placed the student's own answers to A.1, the Insecticide problem (in the short open-response format), and A.7, the identical problem (as an MCQ), contained in Appendix IV, before them and asked:

*B.1 'Which of these two methods of questioning do you consider tested your understanding more thoroughly?'

(student answer)

If student did not give a reason I asked 'Why?'

'Do you generally find this for MCQ's, or does your comment apply to this particular question only?'

Results

After re-reading their two answers, all but two students made a firm choice. When asked whether this held in general, a few students changed. The results for the HB and NS students are shown in Table I.

* In 1977 pilot studies, during post-test discussions, I asked which method of questioning students preferred. Their answers tended to slip, not unnaturally, into considering ease and chance. Therefore I reworded this question to 'thoroughly', to convey more clearly the sense of 'honestly' and 'accurately'.


Table I. THE TYPE OF QUESTION WHICH TESTS UNDERSTANDING MORE THOROUGHLY

<table>
<thead>
<tr>
<th></th>
<th>HB</th>
<th>HS</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR more thorough</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>5</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>O→</td>
<td>7</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>MCQ more thorough</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>10</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>O→</td>
<td>8</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>usually MCQ easier *. change</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>*. In general:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OR more thorough</td>
<td>15</td>
<td>9</td>
<td>24</td>
</tr>
<tr>
<td>MCQ more thorough</td>
<td>15</td>
<td>11</td>
<td>26</td>
</tr>
<tr>
<td>Depends on particular question</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Table I shows that students were equally divided about which method of questioning tested their understanding more thoroughly.

Level of difficulty of question

For this question P=0.62 for these 52 students. Of the 20 students who selected an incorrect response of the MCQ: 12 chose the MCQ as more thorough, and 8 chose the OR as the more thorough. Thus it did not appear to make any significant difference to their selection whether or not they got the MCQ correct. (Students did not know whether they had marked an incorrect alternative when they were asked which method tested more thoroughly).

10.2 REASONS FOR THEIR CHOICE

Some students gave more than one reason. I have recorded the frequency of reasons, not the distribution of students. I have included students' code numbers in the examples for possible reference back to the master Table VIII,
Chapter 8, but note that these code numbers do not give a complete list of all students giving a particular reason.

(a) OR. The twenty-four students who believed the OR format tested their understanding more thoroughly gave the following two kinds of reasons:

Thirteen comments supported OR because:

- it gives you nothing and you have to think of everything yourself. (no. 43)
- you have to put it down in your own words. (no. 14)
- it potentially asks for more understanding of the Q. — you can go into it more thoroughly. (no. 4)

Sixteen comments were anti-MCQ:

- if I haven't got a clue they (MCQ) give me one. (no. 3)
- MCQ pick out one tiny point and you can't show what you do know. (no. 5)
- it gives limits, restricted to one in four, and you can make a stab because the answer is there. (no. 20)
- it can be ambiguous, and you can get it wrong even if you know it. (no. 25)
- the answer stood out/circling easier. (no. 27, no. 30)

(b) MCQ. Reasons why the other half of the students believed that in general, multiple-choice, MCQ, test their understanding more thoroughly fell into three groups.

Seventeen comments referred to the level of understanding required:

- the alternatives can confuse you if you don't know your work inside out. (no. 24 no. 32)
- it (MCQ) gives more ideas, is a more specific Q. (no. 11)
- there was a subtle difference in those responses, you have to identify the cause and put it down precisely. (no. 3)

Eleven commented on testing the ability to reason:

- it challenged my thinking more, I had to read everything and think through to a solution. (no. 17)
- it put different ideas into my mind to expand on before selecting one - in the OR I stuck to one particular aspect. (no. 51, no. 16)
- you've got to relate and interpret what's already written. (no. 4)

Five comments referred specifically to their use in exams:

- you've got to know your work more accurately, it's right or wrong, whereas in the OR you can be partially right and get some marks. (no. 32)
- you have to read all the time, and go from one to another — there's no time to write and think. (no. 26)
- you can't waffle. (no. 28, no. 12)
To further test the reliability of these findings, that many students consider MCQ a difficult and more thorough method of questioning, I identified the eight students who had shown sound understanding for the concept of natural selection. Of these eight:

3 had selected the OR as more thorough, and
5 had selected the MCQ.

Overall, these comments are perhaps best summed up by one of the 1977 pilot studies students, who explained:

"It's not that they (MCQ) are easier, they just test different things — in the OR you're asked a question without being given any further information to deduce the answer from, i.e. the answer has to come from himself; in the MCQ the answer is there, to be identified, so it's more a "reason it out".'"

Rather unexpectedly, the entire first year 1978 group of Biology students were approximately equally divided between these two styles of short objective questions — the short open-response (OR) and the multiple-choice question (MCQ) — as testing their understanding of specific topics more thoroughly.

### 10.3 The Role of Learning Style in Examination Essays

At the beginning of the second term, the Human Biology students were set a 2-hour progress exam. Included in this was a choice of one essay out of three, each essay question being based on a different section of the first term's course. The other section of the paper comprised 9 short answer questions. Students were advised to spend about one hour on each section, each section containing 50% of the marks.

**Analysis of the 3 essay questions:**

The three questions showed very different styles in their wording. They were written by the three staff members of the Department who had covered the respective topics in lectures. As part of these observations I interviewed various staff members about their lecture presentations.
Each of them volunteered comment on the essay questions, and this has been included. Informal discussions with small groups of students were also held to learn students' perceptions of lectures.

**Question 1.** 'What are the major gaps in our knowledge and understanding of human evolution?'

The question asks for 'gaps in our knowledge', but does not make clear whether this is intended as a simple 'time-gap' in the fossil record, or 'anatomical gap', where there is a discontinuous jump in particular characteristics, making the sequence of lineage uncertain. In either interpretation, considerable specific detail, and some account of the postulated sequence from primates to Homo sapiens, is obviously required, i.e. an analytic component.

Any essay on the 'understanding' of human evolution requires an overview. Rather than ask students to demonstrate what they have learned, and what is known, the question obliges them to re-order their knowledge to consider what is not known; a holist style is required also. Therefore a complete answer to this question requires both analytic and holist (A+H) styles.

During informal discussions the lecturer criticized the question as being very difficult. It went 'beyond the content of lectures', on what was required, and also 'did not enable students to adequately show what they had learnt.' A more 'straightforward' question, giving more information on what is required is planned for next year. These comments suggest an implicit agreement with my analysis of the style of this question. Further, it appears that the 'holist' component may be omitted from next year's question.

**Question 2.** 'Describe any individual or social behaviour mechanisms, observable in lower animals, which you consider can be identified in man.'

This question requests a straightforward description of an unspecified number of behaviour patterns common to certain animals and man. As such,
the question could be answered in a series of paragraphs each devoted to a specific example. The question does not suggest any level of 'lower animal'. No consideration of the significance of common behaviour patterns to the evolution of human behaviour is asked for. Without such an overview, Q.2 is an analytic style question.

During informal discussions, one of the two lecturers presenting this topic specifically pointed out that the ethology essay question was not directed to any particular lecture(s). In contrast to the other two essays, this ethology essay question had been re-worded every year. He had not wanted to 'direct' students into a particular line of thought, but wished them to develop their own. He agreed that in retrospect, the idea of any 'line of thought' was not contained in the question, and that a series of discrete paragraphs, each containing an example, would adequately answer this 'essay' question.

**Question 3.** 'Discuss the extent to which neurophysiology can be used to explain human behaviour.'

This broad question covers a enormously complex topic for a one-hour essay. Neither the line of argument, nor particular kind of examples are 'cued' in the question. Thus the student has to create his own theme and select relevant supporting evidence. Q.3 is written as a holist style question.

During informal discussions, the senior lecturer agreed that this was the least analytical of all the three questions, but commented that the aim of the three questions was to be equivalent, each requiring the same amount of thought to write a complete answer. He agreed, however, that from the students' perspective, they would appear very different questions.

With such a complete spectrum of learning styles contained in the
wording of this set of essay questions, I was interested in determining the degree of 'style-cueing' or consciousness, which influenced the student's choice of essay in the examination.

10.4 CONTENT VERSUS STYLE

How important was the style of the wording of the questions in influencing students' selection? Two weeks after the exam, at the beginning of a normal course lecture, I showed an overhead transparency containing the questions and asked the students:

'Why did you choose the essay that you did, i.e. any reasons or points which crossed your mind, that you can recall. I'd like you to write down these reasons, and include your name.'

I did not mention any specific 'cues' such as topic, wording or style. Nor did I specifically ask for reasons in order of priority.

Method of analysis.

Students' responses were first divided into the three questions and examined. Where content of the question was recorded, the reason was marked 'X'. (e.g. mention of specific topic, factual knowledge). Where style of the question was recorded, the reason was marked '0'. (e.g. 'descriptive essay', 'abstract title', 'too non-specific', 'couldn't relate'). Where students focused on exams, the reason was marked '!' (e.g. get more marks, told there was always a question on it). Very vague reasons, e.g. 'couldn't do the other two' were marked 'DK' (Don't Know). The complete analysis of all sets of reasons, in symbolic form, for each question, is shown in Table II. Students' code nos. (from Table VII, 8.8) have been included and the spontaneous order of ideas, (where more than one reason was given) has been preserved.
Table II

<table>
<thead>
<tr>
<th>Question 1 (n = 13)</th>
<th>Question 2 (n = 11)</th>
<th>Question 3 (n = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Reasons</td>
<td>No. Reasons</td>
<td>No. Reasons</td>
</tr>
<tr>
<td>1 X</td>
<td>12 X</td>
<td>3 X</td>
</tr>
<tr>
<td>2 XOX</td>
<td>5 XXXXO</td>
<td>9 XOX</td>
</tr>
<tr>
<td>7 XOXOX</td>
<td>6 XO</td>
<td>17 XX</td>
</tr>
<tr>
<td>3 XO</td>
<td>13 O</td>
<td>23 !XX</td>
</tr>
<tr>
<td>10 X</td>
<td>14 XO</td>
<td>24 XXXO</td>
</tr>
<tr>
<td>11 X</td>
<td>15 XO</td>
<td>27 abs.</td>
</tr>
<tr>
<td>16 !X</td>
<td>20 OX</td>
<td>DK= Don't Know</td>
</tr>
<tr>
<td>19 X</td>
<td>21 XOO</td>
<td></td>
</tr>
<tr>
<td>22 XD</td>
<td>2 DK</td>
<td></td>
</tr>
<tr>
<td>29 DK</td>
<td>18 DK</td>
<td></td>
</tr>
<tr>
<td>30 DK</td>
<td>25 DK</td>
<td></td>
</tr>
<tr>
<td>26 abs.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Content 1st — 8    Style 1st — 1    Exams 1st — 1
Style 1st — 1      Style 1st — 3      Exams 1st — 0
Exams 1st — 1      Exams 1st — 0      Exams 1st — 1

(nos. 28 and 31 absent from exam)

Taking the three questions together, for these 30 students, Content was listed as the 1st reason by 17 students, (57%), and was recorded as a minor reason 32 times. Style was listed as the 1st reason by 4 students, (13%) and was recorded as a minor reason 20 times. Exams were listed as the 1st reason by 2 students. Vague answers were given by 5 students.

No answer (due to absence) from 2 students.

These results showed convincingly that these students selected their essay primarily on the basis of content, i.e. the topic of the question. The style, or wording of the question was of secondary consideration.

I have included examples for each question. The points used to determine the code in Table II have been underlined, and the code is included for each example. The students' overall learning style, from Table VII, 8.8 is in brackets at the end of each example.
(a) **Content first reason.**

Q.1 'It was a process of elimination — I knew evolution more thoroughly than the other two. The others seemed more abstract titles.' (Code XO) (no. 22, Analytic, high level of integration)

Q.2 'Q.1 required a knowledge of facts, names and dates, which I couldn't rely on, in Q.3 the wording "Discuss the extent of" was off-putting. Q.2 gives you scope for individual ideas and general knowledge and waffle.' (Code X00) (no. 21, versatile).

Q.3 'I felt I knew more about evolution from reading, but the nerve essay was more difficult and therefore more challenging. But I read the Q. wrong and took an anatomical view. I'm very weak on the subject of primates.' (Code X00X) (no. 9 versatile, high level of integration).

The students' perception of which were 'more factual' essays was not always consistent. For example two analytic students chose Q.1 and Q.2 because:

'Q.1 encompassed a wider area of knowledge, so was more stimulating than the other two hard-fact essays (which they both were).' (Code XX) (no. 1 analytic).

Alternatively:

'I though Q.2 had most scope for reasoned argument and discussion. The other two were more factual, therefore not open to so much discussion.' (Code OX) (no. 20, analytic).

Only one analytical student chose Q.3, primarily because of content:

'It was the only one I could. I didn't do any work at Christmas. But I still would have done this — it's the only subject of interest so 'ar. I didn't have the facts for the others. I like that sort of question, you can take it from real life.' (Code XXXO) (no. 24, analytic).

(b) **Style as first reason.** Only four students gave a reason classed as 'style' first. One has been shown above (no. 20). The other three are included below, showing which question their comments applied to:

Q.1 'Evolution follows a more logical progression. I hate discussion questions. Could have attempted Q.2 but I lacked the knowledge.' (Code OOX) (no. 4, analytic, high level of integration).

Q.2 'It was based on thought and experience. Q.1 was too practical and needed great knowledge of cases, Q.3 also needed concrete facts and deep prior revised understanding.' (Code OXXXO) (no. 5, analytic).

Q.2 'Elimination. Title most interesting, and have just read an article on "Manwatching" by D. Morris' (Code O) (no. 13 versatile).
(c) Exam-conscience or consciousness (Miller and Parlett 1974) as first reason:

Q.1. 'I was told there was always a question on it, so I included it. I like evolution a bit. I thought the other two would not be answered as well as Q.1' (Code :X) (no. 10, analytic)

Q.1. 'I obviously thought I could get more marks on it! I had done very well in my knowledge of the other two questions than this one. I didn't know this one particularly well. (Code :XX) (no. 23, versatile)

(d) Don't know

Finally, the students whose reasons were too vague to classify, e.g. 'the only one I could', 'couldn't do the other two', all were in either the purely analytical or purely holist groups. Overall the versatile students gave the fullest account of the reasons for their choice, usually commenting on all questions.

10.5 DISCUSSION

For these Biology students, presented with this set of essay questions, the content or topic of the question clearly was of more importance in determining their choice, than was the style of the question. After only one term of their course, the degree of exam-consciousness (Miller and Parlett 1974) was clearly not highly developed. It would be interesting to observe whether this clear-cut choice of content before style continues throughout their course; or whether the importance of content is a legacy of the heavy knowledge-orientated science exams at A-level, (i.e. learned); or indeed whether it is innate.

These comments show, I believe, that learning style, i.e. how a student perceives a task, is a very real component of these students' learning, in both their course and the assessment procedures which determine their final success. Those students who have not shown versatility may be at a disadvantage in coping with the different requirements of the course. 'Learning how to learn', including a discussion of both learning styles and levels of integration, could be of value to the students as part of their tertiary biological studies.
This Chapter completes the data analysis of this project.

10.6 SUMMARY

1. MCQ:OR. Human Biology students were equally divided over whether MCQ or short Open-Response (OR) questions tested their understanding of biological problems more thoroughly. This division was also seen among the eight students with sound understanding of the concept of natural selection.

2. Essay: Content or Style. Seventeen students (57%) gave subject content as the primary factor determining their choice of essay. Style was listed as the primary factor by four students (13%), but was frequently an additional factor. 'Exam-cueing' was mentioned by only two students.
CHAPTER 11 LEARNING FOR TOMORROW

My original aim in this project was to explore tertiary Biology students' understanding of the concept of evolution by natural selection, and to identify and investigate the origin of common misconceptions which I had previously observed as a teacher of Biology and Environmental Science. By using a problem-solving approach I established, both in the pilot study and in the main study, that only 15% of the student populations tested, were able to consistently identify and explain unfamiliar or novel problems based on natural selection. These observations are contained in Chapters 3 and 5 respectively. These students had studied Darwinian evolution as part of their A-level Biology studies and therefore 'knew' that Darwin's theory is based on the selection or survival in nature of 'the fittest'. Their difficulty was not in having the knowledge, but in being able to use their knowledge in unfamiliar problems. The concepts identification question, following the problems, showed that more students could identify the underlying concept than were able to correctly apply natural selection in their explanations.

Similarly, in exploring their understanding of 'life' (Chap. 6) most students 'knew' (i.e. could recite) the seven characteristics of life, shown clearly in the Fire problem. But in both familiar, (the Fire problem) and unfamiliar, (the Rock problem) problems many were unable to apply this knowledge to reason through to a solution. According to Ausubel's definition (1968) the ability to be able to transfer previously learned concepts and apply them correctly to unfamiliar problems of the same concept has been used as the criterion of meaningful learning throughout this project.

In Chapter 7, I described preliminary observations of students' perceptions of time-scales and rates of change. The possible reversal of
decentration associated with students' future time-orientation and
the difficulty in relating two concurrent time-scales are intriguing
observations which suggest a major further extension into this aspect
of student perception.

In reporting all these results I have used tables as the most
efficient way of recording both the range of responses and their frequency
of occurrence in the study population. In this way I have attempted to
overcome one of the problems of studies using very small numbers of
volunteer students, whose observations give no indication of their
frequency in a wider population. This use of tables therefore has been
an attempt to quantify and reveal both major and minor problems and
misconceptions associated with the concepts under study.

These results led me to consider the wider problems of how students
acquired or integrated new knowledge into their existing framework of
knowledge and experience. A literature search (1.4) revealed a rather
confused picture of cognitive aspects of learning, with multiple and
imprecise criteria used to define various 'unique' dichotomies. From
my own observations of learning styles I drew up a model of the learning
process which enabled a comparative distinction to be made between some
of the dichotomies describing student learning:

\[
\text{learning process} \quad \rightarrow \quad \text{input} \rightarrow \text{intellectual + existing skills knowledge} \rightarrow \text{learning outcome.}
\]

In the recent literature on individual differences in student
learning, many dichotomies associated with the learning process have been
grouped rather loosely together as students' learning (or cognitive) style.
Under this broad umbrella the skills of analysis, of integrating and
relating new ideas to existing ones, and different outcomes of learning
have all been grouped together.
The observations in Chapter 8 demonstrate, I believe, that such a broad description of the concept of 'learning style' is inadequate and should be more clearly defined.

According to the components of the model of the learning process drawn above, 'learning style' most accurately belongs to the class of intellectual skills which an individual possesses and uses to 'learn' and interact with his environment. I have defined 'learning style' as the way a student perceived a problem or a task. I identified two distinct learning styles which were shown for descriptive tasks of both familiar and unfamiliar topics. In one style, students consistently broke the task into its parts — this I called analytic style. In the other style, which I termed holist style, students 'saw' the task as a whole, and as part of its environment. Because there were many instances of students showing versatility of styles (i.e. showing characteristics of both), I do not believe that these differences can be adequately explained as a continuum of one style, or as mutually exclusive styles, but as two independent learning styles of equivalent ranking. This is in closest agreement with Thorsland and Novak's analytic-intuitive dichotomy.

The results overall (Chapter 8) showed that this population of tertiary Biology students fell into two main categories, analytic and versatile. The holist category overall was very small for the biological tasks used in this project.

Since 50% of the students were versatile, i.e. showed the ability to use both analytic and holist styles, and the other major group showed analytic style only, the possibility that one style precedes another, i.e. analytic style develops before holist style, should be raised. This particular project cannot add data which either strongly supports or strongly refutes this — a longitudinal study would be the best method
to study this possibility. The observation of the singular holist group (on these tasks both individually and collectively) suggests that holist style is not NECESSARILY a later, more complex style than analytic style. Neelkopf's (1973) work on the identification of both field-dependent and field-independent five-year-old children suggests equivalent rather than sequential development of learning styles. This aspect is worth pursuing as it could add to our understanding about the mutual independence or relatedness of these two basic learning styles, to their equivalent or hierarchical ranking, and in addition further characterize learning styles as independent of levels of integration.

The variation in the distribution of students into learning styles for different tasks can be accounted for by the particular styles shown by versatile students for individual tasks (Chap. 8.8). This highlights the need to give students a range of tasks in any studies of this nature, rather than the rather singular activities which have been commonly used. Is this similar to standard measures of IQ, where a battery of tests is employed?

In Chapter 1, I reviewed literature which suggested that holist style (or its corresponding equivalent in other dichotomies, see 8.1), may be related to creativity; but apart from a brief mention in Chapter 6, I have not explored the complex human activity called creative thought. The relationship between insight, intuitive thinking, holist style and creative thinking has therefore not been resolved by this small project. Similarly there may be some correlation between holist style and the popular term 'lateral thinking' (de Bono 1967) which is also beyond the scope of this thesis. The relationship between a 'hypothesis-testing' approach and a 'spectator' approach, described by Witkin (1977) in his field-independence/field-dependence dichotomy was also observed in my analytic/holist learning styles dichotomy, for the hypothesis-testing task (the Rock problem). The increasing recognition of a 'holist' or
'intuitive' style as a distinctive way of perceiving a problem or task seems to confirm Hilgard's (1962) forecast of a re-emergence of some of the earlier Gestalt ideas of perception and learning, described briefly in Chapter 1.1 (see p.7).

The use of an unfamiliar (i.e. not formally studied) biological topic, Immunity, in the first descriptive task highlighted the difference between learning style and the level of integration attempted by students, (i.e. the linking of this new topic into their existing knowledge.) Those students who attempted this (sometimes making incorrect links, as shown in Chaps. 3, 5, 8), for both the familiar Graph task and the unfamiliar Immunity task were called 'high' in their level of integration. The '+' of the model most accurately represents this step in the learning process, which I believe is similar to some aspects of Pask's (1976) operation/comprehension learning and Marton's (1975) surface/deep processing.

The variation in levels of integration between these two tasks may be related to the content of the task as well as to any specific characteristic of a student. Time did not permit further exploration of this interesting observation.

Ultimately, the assessment of any learning has to take into consideration the outcome of the learning process. Marton and Saljo (1976a) attempted to demonstrate a relationship between levels of processing and outcome. This, however, does not mean they are one and the same thing, and that by measuring outcome, one is also measuring processing. The learning outcome, (i.e. the end-result of the model described above) distinguishes the dichotomies of Wertheimer (1945) rote-memorizing/productive-thinking, and Ausubel (1968) rote/meaningful learning, from all other dichotomies, which are associated with other aspects of the learning process. One difference between learning styles on the one hand, and levels of integration and learning outcomes on the other, is that the dichotomies in this latter group are clearly hierarchical. This may not
be so in the case of learning styles. Thus the time-worn controversy over whether intellectual skills and abilities are hierarchical (Vernon 1950) or equivalent (Thurstone, 1938, Guilford 1967) still exists today.

The significance of both learning style and level of integration to learning outcome was shown in Chapter 9, when those students who had been shown to have a sound understanding of natural selection (using separate problems, Chap. 5) were identified. The majority belonged to the versatile learning style group using a high level of integration. This observation indirectly confirmed, I believe, the validity of all these separate sets of observations, contained in this project.

The differences in learning styles, the study of conceptual learning rather than content learning, and the use of problem-solving as a valuable tool in teaching and learning, all have wide implications for education.

Recently Novak (1977) argued that 'human understanding is based on the concepts that exist in a society, and which are the tools used by humans to solve problems'. He recommended that concept learning become the model for major revision in education. In criticizing current education practices Novak follows a long line of critics, led by Dewey (1916) extending nearly throughout this century. There have been important developments, however, which make such a revision increasingly desirable and urgent.

* * *

Historically, schools have been involved in the vertical, authoritative transmission of knowledge from one generation to the next. In a very slowly changing world, where the future was a continuation of the past, this was appropriate. Within this century, however, Toffler's '800th life time of man' (1971), a series of events have occurred which, I believe,
makes this model of learning both inadequate and impossible to maintain.

1. The great explosion of knowledge that has occurred in all fields of human endeavour means it is now no longer possible to 'know' all but a very narrow specialized area of knowledge.

2. The development of technology which gives cheap and rapid spreading of knowledge (through books, the media and networks of global communications).

3. The development of technology — the computer and micro-processor — which can store, categorize and process huge quantities of detailed factual knowledge with immediate accessibility.

In the thirty years since the Second World War, the rate of technological change has accelerated at an unprecedented rate, resulting in an accelerated rate of change of society. Together with the exponential growth of the human population, this has altered the balance of stabilizing ecological forces in the natural environment. Education has been slow to respond to the changing needs of our society, but the mounting anxiety about the quality of human life, the environmental deterioration and the diminishing resources of this small planet is beginning to break into the classroom at different levels. Texts, (e.g. Simmons 1974), summarizing conflicting arguments and opinions rather than merely 'doomwatching', and objective articles written for the general population all carry the same message:

'We hope that these articles ... convey a sense of the dimensions of man's impact on the ecosphere, and correspondingly of the fundamental sociological and technological changes required to alleviate that impact.' (Ehrlich, Holdren & Holm 1971)

Mesarovic and Pestel (1975) in their second report to the Club of Rome describe the need to take a 'global' view of environmental problems, and to consider both the short and the long-term aspects, for 'mankind is at a turning point'.
The majority of courses at secondary and tertiary level, however, are overloaded with factual content, requiring students to 'fill-up' in order to pass the largely content-orientated forms of assessment, where 'how much' is more important than 'how' or 'why'. Elton and Laurillard (1979) have recently reviewed trends in research on student learning towards holistic rather than psychometric evaluation. Novak (1977), Dahlgren and Marton (1978) and others have urged that education should focus on the process of learning rather than the content. In this I am in complete agreement. Education should be directed towards developing the ability to use the knowledge which is so rich a part of our human culture. Man, unique among animals in the complexity of his brain, has the capacity to reason, evaluate, question and forecast, both creatively and objectively. These are the intellectual skills which are necessary in order to use the knowledge that exists. Learning to 'think biologically', i.e. to organize one's biological conceptual understanding to solve biological problems, is an active process, not the end-product of a course of study. This project has demonstrated that the majority of these Biology students are entering tertiary studies poorly equipped with these skills, as judged by their difficulty in solving unfamiliar biological problems.

One of the most interesting observations in this project was the identification of relatively consistent learning styles shown by these students. The educational implications of basic differences in learning has also been recognized by others. Novak (1977) distinguished 'the logical presentation of material where progressive differentiation of a concept is done in a serial order, but where the integration of concepts is left to the student'. This, according to Novak, is the most common method of presentation in current textbooks and by most teachers.
Psychological, or integrative presentation, on the other hand, 'deals with concepts at all levels of the conceptual hierarchy in a cyclic fashion.' Novak's two 'styles of presentation' seem identical with the two learning styles identified in this project. Similarly Pask and Scott (1972) stated that 'most examinations favour serial recall', but that in developing strategies of learning it was important to be able to see both 'the woods' and 'the trees'.

Recognition of a variation in learning styles has considerable significance to many aspects of curriculum development. It suggests the inclusion of integrated rather than totally specialized subject courses. Most methods of presentation of material (e.g. style of lecturing, audio-visual aids, supplementary notes and reading guides), are traditionally heavily content-orientated, i.e. broken into discrete chunks of factual knowledge. Provision of sessions to develop both analytic and holist styles or skills, group vs. individualized learning, the design of laboratory work, and the choice of methods of assessment and style of examination questions, (the last being briefly considered in Chap. 10), can all be designed to encourage students to become versatile in their learning style.

Traditionally, 'scientific method' has been synonymous with 'analytic method', and scientific experimentation has involved the isolation of the problem under investigation and the rigorous control of all known variables. This approach has led to greater understanding in the physical sciences. It is becoming increasingly apparent that the complex biological sciences cannot be fully understood by this approach, for the 'whole' of a complex interrelated system is more than just the 'sum of its parts'. Popper (1957) stated that 'holism is said to be characteristic of biological phenomena in general and the holistic approach is regarded as indispensable...'
I would like to mention two areas of biological education in which a holist-style of thinking has particular significance. One is in environmental education, for it is not enough to study problems in isolation from their environment. The classic illustration of this was the experimental testing of the effectiveness of DDT in controlling the malarial mosquito in Africa. As an isolated system DDT was highly effective; but on a wider scale, both spatial and temporal, the interrelated effects on bird egg-shell fragility and consequent devastation of bird populations was an unpredicted ecological tragedy. (Carson 1959)

The addition of a holist component to the traditional analytic scientific thought also has direct application to medical education. The art of medical diagnosis certainly requires students to learn the classical symptoms of known diseases — this is an analytic approach to an illness. However in practice the illness is presented as an unknown problem, requiring a holist style in order to identify significantly important underlying concepts in order to correctly diagnose the illness. In an increasingly stressful society, illnesses which include environmental and psychological rather than only physiological components will require the development of the skill of seeing the 'whole' of the problem, i.e. the patient in relation to, not in isolation from, his environment.

In objective scientific method, the analytic approach has involved increasingly more detailed analysis of a topic. The addition of a 'holist' approach may indirectly develop skills of creative speculation, which I believe has a legitimate place in scientific thought, and in education generally (Torrance 1970).

Whether differences in learning style are innate (i.e. natural characteristics of an individual) or learned, whether they are stable over time, are intriguing questions emerging from this project (see Chap. 8).
In any case, learning experiences can be designed to encourage their
development. Active curricula, in which students participate, critically
examining their own and other's ideas, are needed. Problem-solving, as
a method of teaching and learning concepts in action (see 2.9) is, I
believe, one of the most useful tools for conceptual learning. Although
they were used in written tests and task interviews for the purposes of
this research, the problems designed for this project could be transferred
directly into formal studies of these concepts. They should also act
as examples for other disciplines. As education loses its narrow
definition of youth-related full-time studies, 'student' populations
will inevitably become more heterogeneous and educational backgrounds
increasingly diverse. A problem-solving approach to conceptual learning
can accommodate and capitalize on such diversity of experience.

* * *

The major conceptual theme of this project has been the understanding
of evolution by natural selection. This concept was not chosen at random.
I believe it is the most important single biological concept that needs to
be understood, if we are to begin to understand the nature and dimensions
of environmental problems that exist today. The problems I designed for
this 'biological' project were in fact 'environmental' problems, both
biophysical and sociological, all concerning evolution. Problems of
chemical pesticides, of the over-use of antibiotics, of the extinction of
species, of the exponential growth of the human population, of the
definition of 'human' life, of the variation of skin colour in the races
of man, and of the rate of change of our technological society — these
are all real, urgent problems involving an understanding of Darwinian
and cultural evolution. In teaching the concept of natural selection, the two crucial first steps in the process, (see Chap. 3), namely the diversity in all species and the change in the environment relative to generation time, must be clearly identified, emphasized and applied to further problems until they are meaningfully learned by students. The observations contained in this project demonstrate that we have not achieved this for the majority of senior secondary Biology students. If our education system is to achieve its aim of preparing students to take part in society as responsible adults, then it must develop the intellectual skills and the conceptual understanding which will enable them to use the wealth of knowledge that we have. In doing this, education will become a dynamic leader of, rather than a passive responder to, social change, for the future is to be created, not endured.

In Chapter 7, I focused on these students' future time-orientation and perception of the accelerating rate of environmental and social change. Their professed adaptability to change was not reflected in the few predictions identified in forecasting their personal futures. In a rapidly changing world, reliance on the facts of the past must be challenged by the predictions of the future. As the human impact on the biosphere has suddenly threatened the finite carrying capacity of the Earth, there has arisen the need to look ahead and attempt to forecast the consequences of man's impact.

I believe it is the responsibility of this technological generation to include in its culture the intellectual skills necessary to enable the meaningful learning of the fundamental biological concepts on which all life on earth depends; so that our children, and their children in turn, will be able to read and understand Darwin's closing words of his great contribution to biological thought (1859):

'...from so simple a beginning, endless forms most beautiful and most wonderful have been, and are being, evolved.'
REFERENCES


Dahlgren, L. O. (1978) Qualitative differences in conceptions of basic principles in economics. 4th internat. conference on higher education, University of Lancaster.


APPENDIX I. AUSTRALIAN H.S.C. RESULTS 1976
The Essay Question:

15. Weevils of the family Curculionidae are widespread in Australia and throughout island groups in the South Pacific.

The relative numbers of species of weevils found in the various regions is indicated in the following diagram:

Observations on these weevils also reveal that:

(a) all species found at B, C, and D are also found at A.
(b) there is a particular species (species X) which is found at A, B, D, E and F but which is missing from C.
(c) there is a species (species Y) which is found only at E.
(d) there is a species (species Z) which is found only at E and F.

Write a carefully reasoned essay to explain these observations.

--[12 marks]--

Results:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>10,235</td>
</tr>
<tr>
<td>Mean</td>
<td>2.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>1.93</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.411</td>
</tr>
</tbody>
</table>

Distribution of Students:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor (0-3)</td>
<td>68.1%</td>
</tr>
<tr>
<td>Moderate (4-7)</td>
<td>29.8%</td>
</tr>
<tr>
<td>Good (8-11)</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

Details kindly supplied by Dr. M. Martin, Chief Examiner in Biology and Chairman, Biology Standing Committee, VUSEB, Melbourne, Australia.
APPENDIX II.  CONCEPT MAP OF EVOLUTION
Development of map:

Vertical. The relationship to evolution of three lines of association, the roles of the environment, the organism and genetics are shown. The three basic concepts are shown on the base (most sub-ordinate) line. Time has been shown as an independent variable.

Horizontal. From the base-line, reading upwards: the second line lists the diversity of individuals within these three lines, the third line shows the processes which operate to change this diversity, the fourth line shows the effects of these processes on populations. One effect is that the population as a whole becomes progressively better adapted to a changed environment; the other, isolation of a population resulting ultimately in the evolution of a new species.

The two red arrows show two common misconceptions.
1. that organisms can adapt genetically to a change in the environment, (i.e. adaptation is seen as a process, not an end result),
2. that a change in the environment causes appropriate mutation.
APPENDIX III. STAGE 1. WRITTEN TEST

Date: ...........................................

Name: ...........................................

Sex: ............................................

Birth-date: ....................................

Current Course (and year): ..................

Career Plans (e.g. teacher, doctor): ....

Educational Details

<table>
<thead>
<tr>
<th>School</th>
<th>Subjects</th>
<th>Results</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or equivalent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U-GRADE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Indicate: 

A: pass grade obtained
F: failed
S: studied but did not sit

If you studied A-Level Biology:

Name of Textbooks:

This information is entirely confidential, and will be used in the analysis of this project only.
Institute for Educational Technology

CONCEPTS ANALYSIS PROJECT 1977—MB

Date: ........................................
Name: ........................................ Sex: ...................................
Birth-date: ....................................

Current Course (and year): ......................................................
Career Plans: (e.g. teacher, doctor): ........................................

Educational Details

<table>
<thead>
<tr>
<th>School</th>
<th>Subjects</th>
<th>Results *</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Level or named equivalent</td>
<td>1. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td>O-Level or CSE Grade 1</td>
<td>2. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td>* Indicate: A {pass grade obtained</td>
<td>3. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td>E }</td>
<td>4. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td>F (failed)</td>
<td>5. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td>S (studied but did not sit)</td>
<td>6. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td></td>
<td>7. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
<tr>
<td></td>
<td>8. ..........</td>
<td>..........</td>
<td>.....</td>
</tr>
</tbody>
</table>

If you studied A-Level Biology:

Name of Main Textbook: ......................................................

This information is entirely confidential, and will be used in the analysis of this project only.
1. When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed. Explain why you think this may be so.

2. Scientists have warned doctors of the danger of their increasing use of Antibiotics (e.g. penicillin) for treating minor illnesses. What is the reason for their concern?
3. Last century, rabbits were introduced into Australia from England. They flourished and quickly spread, causing serious crop damage. In an attempt to reduce rabbit numbers, a strain of myxomatosis virus (which caused a fatal disease in rabbits) was introduced into the countryside. Initially, thousands of rabbits died.

Several years later, however, the rabbit population had reached an alarming size again. Myxomatosis virus was still present, but, on isolation, was found to be only a very mild strain, causing a non-fatal disease.

Put forward a hypothesis which attempts to explain these observations.

4. What basic concepts or principles are contained in these three questions?
Answer these 3 questions by circling the most correct alternative

1. When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed. The reason why fewer insects are being killed is that:
   A. Mosquitoes which survive spraying develop an immunity to the insecticide.
   B. Many mosquitoes today are descendants of mosquitoes with insecticide-resistant characteristics.
   C. Mosquitoes are adapting themselves to this man-made change in the environment.
   D. The original spraying has caused a permanent mutation giving genetic resistance to the spray.

2. Scientists have warned doctors of the danger of their increasing use of Antibiotics (e.g. penicillin) for treating minor illnesses. They are concerned because:
   A. We will become tolerant to the effectiveness of drugs.
   B. Excessive use of these drugs leads to a diminished sensitivity.
   C. Some strains of micro-organisms will develop with resistance to these drugs.
   D. The drugs will be metabolized more quickly by our bodies, reducing effectiveness.

3. Last century, rabbits were introduced into Australia from England. They flourished and quickly spread, causing serious crop damage. In an attempt to reduce rabbit numbers, a strain of myxomatosis virus (which caused a fatal disease in rabbits) was introduced into the countryside. Initially, thousands of rabbits died. Several years later, however, the rabbit population had reached an alarming size again. Myxomatosis virus was still present, but, on isolation, was found to be only a very mild strain, causing a non-fatal disease.
   A. The virulence of the virus was unstable.
   B. The rabbits developed a resistance to the virus.
   C. Over many generations the rabbits' environment has changed.
   D. The death of the rabbits selected against the virus.

Please DO NOT go back and rewrite Section O/R!
NAME: ........................................... SEX ...........................................
AGE: (Years) ......................
Is English your first language? YES NO
Career plans .................................

EDUCATIONAL DETAILS

Exam board. A-level: ..............................

A-LEVEL RESULTS:

<table>
<thead>
<tr>
<th>SUBJECT</th>
<th>GRADE</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A-level Biology texts:

..................................................

Data collected in this study is completely confidential.

Thank you for your participation

Margaret Brumby.
1. When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed.

Why do you think this is so?
2. About two hundred million years ago, dinosaurs roamed the earth. They were huge creatures, some reaching lengths of over 100 feet. All dinosaurs lived in water part of the time and on land part of the time. Most dinosaurs were plant eaters and they ate large amounts of plants of all types and sizes. The plants they lived on were found in and around water.

Write a short paragraph which explains why you think dinosaurs are no longer found.
3. During this century, many discoveries or events with major biological significance have occurred.

In the following table, fill in the dates as accurately as you can.

Mark off a scale on the 'time-line' below and place the events in it (the letter-code is sufficient).

<table>
<thead>
<tr>
<th>EVENT</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Oral contraceptives developed.</td>
<td></td>
</tr>
<tr>
<td>B. Penicillin discovered.</td>
<td></td>
</tr>
<tr>
<td>C. First 'test-tube' baby born.</td>
<td></td>
</tr>
<tr>
<td>E. First Atomic Bomb exploded on Japan.</td>
<td></td>
</tr>
<tr>
<td>F. You were born.</td>
<td></td>
</tr>
</tbody>
</table>

1978
4. Scientists have warned doctors against the increasing use of antibiotics (eg. Penicillin) for treating minor illnesses.

What is the reason for their concern?
5. To a young child, the flickering flames of fire seem 'alive'.

(a) Why do you think a young child believes that fire is alive?

(b) What other characteristics of fire could be used to support this belief?

(c) Why do you believe that fire is not alive? (assuming that you do!)
6. If you were on the first manned space-ship to land on Mars, what evidence would you look for to determine whether living organisms exist there?
7. When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today, some 20 years later, a much smaller proportion of these insects die when sprayed.

The reason why fewer insects are being killed is that:

A. Mosquitoes which survive spraying develop an immunity to the insecticide.

B. Many mosquitoes today are descendants of mosquitoes with insecticide-resistant characteristics.

C. Mosquitoes are adapting themselves to this man-made change in the environment.

D. The original spraying has caused a permanent mutation giving genetic resistance to the spray.
APPENDIX V. STAGE 2. TASK INTERVIEW SCHEDULE
STAGE 2. TASK INTERVIEW SCHEDULE (including student's sheet)

B.1. **MCQ vs. OK.** [Student's answers to A.1 and A.7 from Appendix IV placed before him.]

'Which of these two methods of questioning do you consider tested your understanding more thoroughly?'

(Answer). (prove if necessary: 'Why?')

'Do you generally find this for MCQ's, or does your comment apply to this particular question only?'

B.2. **Concepts identification question.** [Student's answers to A.1 and A.4 from Appendix IV placed before him, time given for student to re-read his answers before answering.]

'What are the basic concepts or ideas that are contained in those questions?'

B.3. **The Rock Problem.** [the rock (pictured Chap. 6.1 page 127) placed before student]

'If you were out in your vegetable garden and you came across this, how would you go about finding out if it is alive, if it was once alive but is now dead, or if it has ever been alive, i.e. is non-living?'

B.4. **The Skin Problem.** [Large 30 cm x 40 cm) patchwork picture of human skin colour variation (pictured Chap. 5.1 page 109) placed before student]

'If we suppose that man originally arose in one place, say in Africa, where some of the oldest human skulls have been found, then how do you account for the different skin colours that exist in the different races round the world today?'

(Answer)

(a) 'What would you predict to happen to this couple's skin (dark-skinned), if they went and lived permanently in Norway?'

(Answer)

'If they had children born in Norway, what would their children's skin look like?'

(Answer)
(b) 'What would you predict to happen to the skin of this little girl, (very light-skinned) if she went and lived in Africa for the rest of her life?'

(Answer)

'If she married someone of her own race, they lived in Africa, and had children there. What would their children look like, at birth?'

B.5. The web Problem. [Diagram of cob-web (drawn Chap. 6.1 page 128) placed before student.]

'You sometimes hear people using phrases like: 'All of life depends on green plants', or they may speak of 'a web of life'. What do you think people actually mean when they use these phrases? (here is a diagram of a cobweb if it helps you to explain by drawing on it).'

B.6. The Logarithmic time-scales Problem. [Student given the following table, F filled in by me. Further explanation given to two items as described below.]

Fill in the dates as exactly as you can in the following table. Then mark their positions on the time-line below.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The start of recorded human history:-----------------------------</td>
</tr>
<tr>
<td>B</td>
<td>Loevenhoek's discovery of 'little animals': the first observation of bacteria under the microscope: -------------------------------</td>
</tr>
<tr>
<td>C</td>
<td>Charles Darwin's hypothesis of 'survival of the fittest'---------</td>
</tr>
<tr>
<td>D</td>
<td>Watson &amp; Crick's model of the structure of the DNA molecule-----</td>
</tr>
<tr>
<td>E</td>
<td>The human population is predicted to double from 1972 figure (3,500 x 10^5) in: -------------------------------</td>
</tr>
<tr>
<td>F</td>
<td>The birth of Christ:---------------------------------------------</td>
</tr>
</tbody>
</table>

1978
[Further explanation]:

A. 'By this we mean when man first started leaving written evidence of himself, e.g. as cave drawings.'

E. (re-phrased). 'In 1972 the human population was 3,500 million, or 3½ billion. When do you think it will reach 7 billion?'

B.7 Future predictions question. [Three predictions filled in by me, in front of students]

'Can you think of three events that you personally believe are so likely to happen that you feel you could say: "One day, I believe this will happen".  

(Answer)  

'Now will you put a date to these three events'.

<table>
<thead>
<tr>
<th>Likely predictions</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.-----------------------------------------------------------------</td>
<td>____________</td>
</tr>
<tr>
<td>2.-----------------------------------------------------------------</td>
<td>____________</td>
</tr>
<tr>
<td>3.-----------------------------------------------------------------</td>
<td>____________</td>
</tr>
</tbody>
</table>

B.8 Personal future forecast. [Time-line placed in front of student, pointing to B and D where relevant.]

If you saw this line as representing your life, between B, your birth, and D, your death, where would you put yourself on it right now?'

(mark)

'What figure did you have in mind for D, to mark that position?'

(age given)

'That gives you about (50) years. What would you like those 50 years to contain for you, or what do you think they will contain, whether you like it or not.'
B.9 The Graph task. [Large graph (Appendix VII) placed before student.]

'Here is a graph showing the rate of technological change, associated with sending our language a long distance. The date of invention is on the horizontal axis, and on the vertical axis I've marked the number of years it took from the date of invention to the time of wide application. So in the 18th century, it took 150 years* from when the typewriter was first invented, to when it was widely available. In 1962 the first satellite was launched which successfully had beams bounced back to earth, and three years later the commercial Early Bird satellite communications network was in orbit. Would you tell me what you see in the graph?' [to a few students who were not clear on what was intended in this question, I re-phrased the question] 'What does the graph tell you?'

* [pointed]


'Would you like to comment on the effects of a graph of this sort on people's lives?'
B.6
(a) Fill in the dates as exactly as you can in the following table. Then mark their positions on the timeline below.

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. The start of recorded human history:</td>
<td></td>
</tr>
<tr>
<td>B. Leevanhoek's discovery of 'little animals': the 1st observation of</td>
<td></td>
</tr>
<tr>
<td>bacteria under the microscope.</td>
<td></td>
</tr>
<tr>
<td>C. Charles Darwin's hypothesis of 'survival of the fittest'</td>
<td></td>
</tr>
<tr>
<td>D. Watson &amp; Crick's model of the structure of the DNA molecule</td>
<td></td>
</tr>
<tr>
<td>E. The human population is predicted to double from 1972 figure (3,500</td>
<td></td>
</tr>
<tr>
<td>( \times 10^6 )) in:</td>
<td></td>
</tr>
<tr>
<td>F. The birth of Christ:</td>
<td></td>
</tr>
<tr>
<td>1978</td>
<td></td>
</tr>
</tbody>
</table>

B.7
Likely predictions

1. 

2. 

3. 

B.8
APPENDIX VI  STAGE 3.  THE IMMUNITY TASK
THE IMMUNE RESPONSE

STEM CELLS (BONE MARROW) → THYMUS

B-CELLS → HELPER T-CELLS

<table>
<thead>
<tr>
<th>B-CELLS</th>
<th>T-CELLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLASMA CELLS</td>
<td>B MEMORY CELLS</td>
</tr>
<tr>
<td>SERUM ANTIBODY</td>
<td>SMALL LYMPHOCYTES</td>
</tr>
</tbody>
</table>

NON-CELLULAR IMMUNITY (IMPORTANT IN INFECTIONS)

CELLULAR IMMUNITY (IMPORTANT IN GRAFT REJECTION)
APPENDIX VII. STAGE 3. THE GRAPH TASK
YEARS BEFORE WIDE APPLICATION

THE RATE OF TECHNOLOGICAL CHANGE

DATE OF DISCOVERY

1600 1700 1800 1900 2000

TYPEWRITER

TELEPHONE

CHARGEABLE BATTERY

TELEVISION

TRANSISTOR BATTERY

COMMUNICATIONS SATELLITE

SILICON CHIP